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Nukui et al.

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(54) **METHOD AND APPARATUS FOR GRINDING A WORKPIECE**

(75) Inventors: **Mitsuru Nukui**, Toyama; **Shirou Murai**, Kanagawa; **Michihiro Takata**, Toyama; **Tetsuo Okuyama**, Kanagawa; **Muneaki Kaga**, Toyama; **Toyotaka Wada**, Kanagawa, all of (JP)

(73) Assignee: **Nippei Toyama Corporation**, Tokyo (JP)

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(52) **U.S. Cl.** **451/57**; 451/8; 451/44
(58) **Field of Search** 451/44, 43, 57, 451/65, 178, 182, 246, 258, 8

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Primary Examiner—Joseph J. Hail, III
Assistant Examiner—David B. Thomas
(74) *Attorney, Agent, or Firm*—Sughrue Mion, PLLC

(57) **ABSTRACT**

A workpiece **23** formed of a circular thin plate is rotated about its center as an axis L**1**. Each of disk-shaped rotating grinding wheels **27** and **28**, while being rotated about an axis L**3** extending in a direction substantially parallel to the plane of the workpiece **23** and perpendicular to the radial direction of the workpiece **23**, is made to undergo relative feeding movement on both obverse and reverse surface sides of the workpiece **23** along an outer peripheral edge portion **23***a* of the workpiece **23**. Consequently, the outer peripheral edge portion **23***a* of the workpiece **23** is ground by an outer peripheral surface of each of the rotating grinding wheels **27** and **28**. In this case, it is preferred that two grinding wheels **27** and **28** for rough grinding and finish grinding be provided as the disk-shaped rotating grinding wheels, and that rough grinding and finish grinding are performed by the same station.

23 Claims, 16 Drawing Sheets

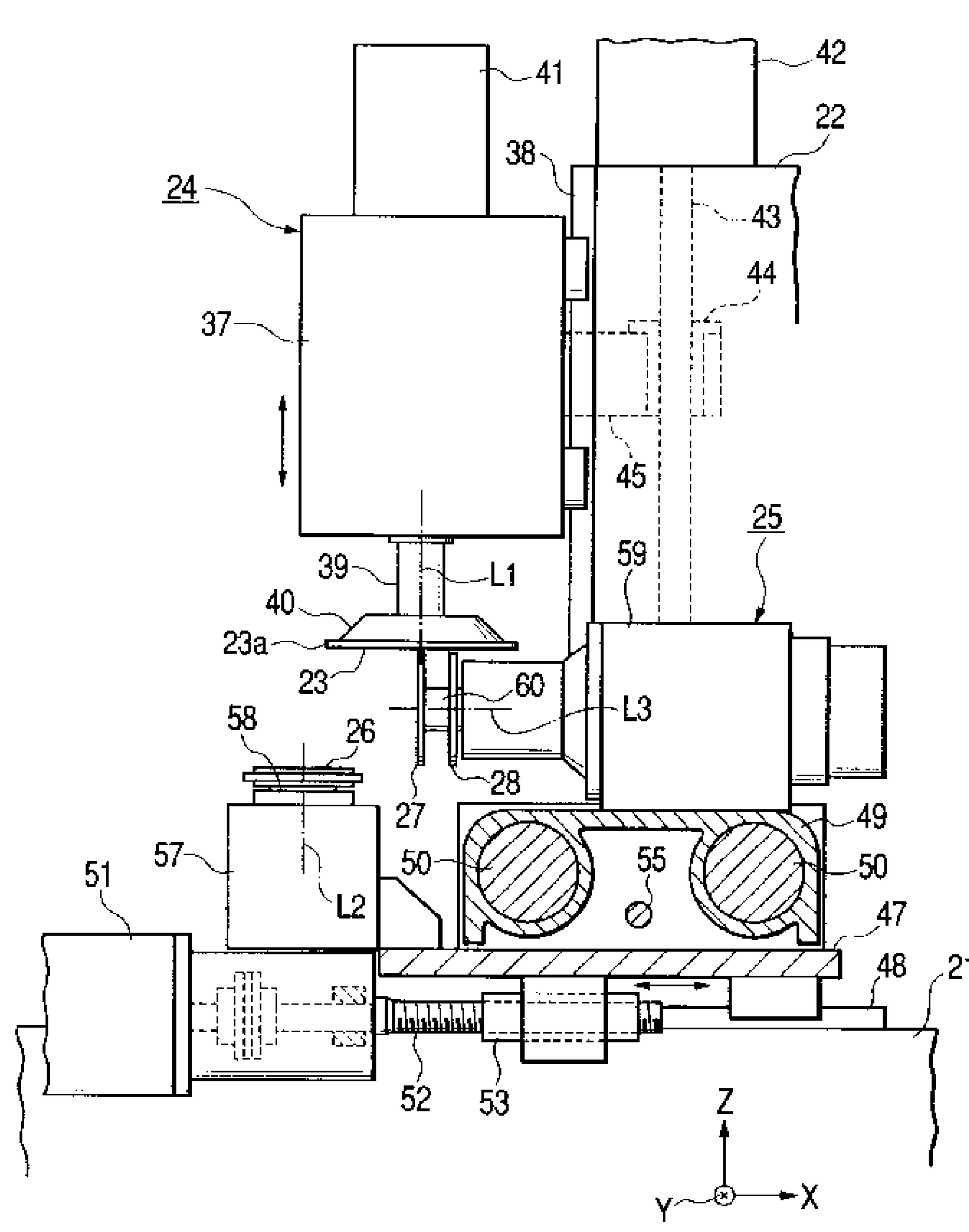

FIG. 1

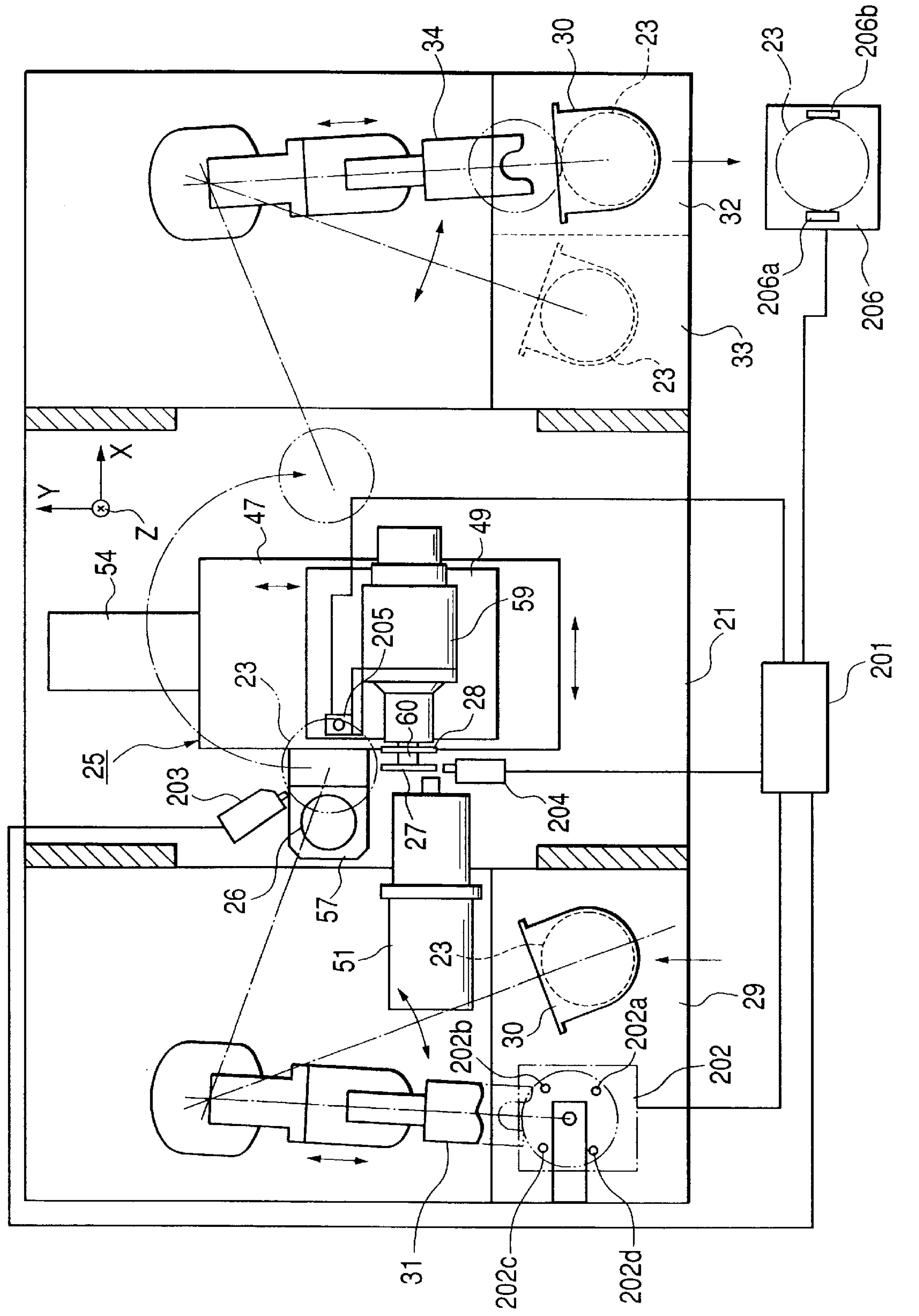
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FIG. 2

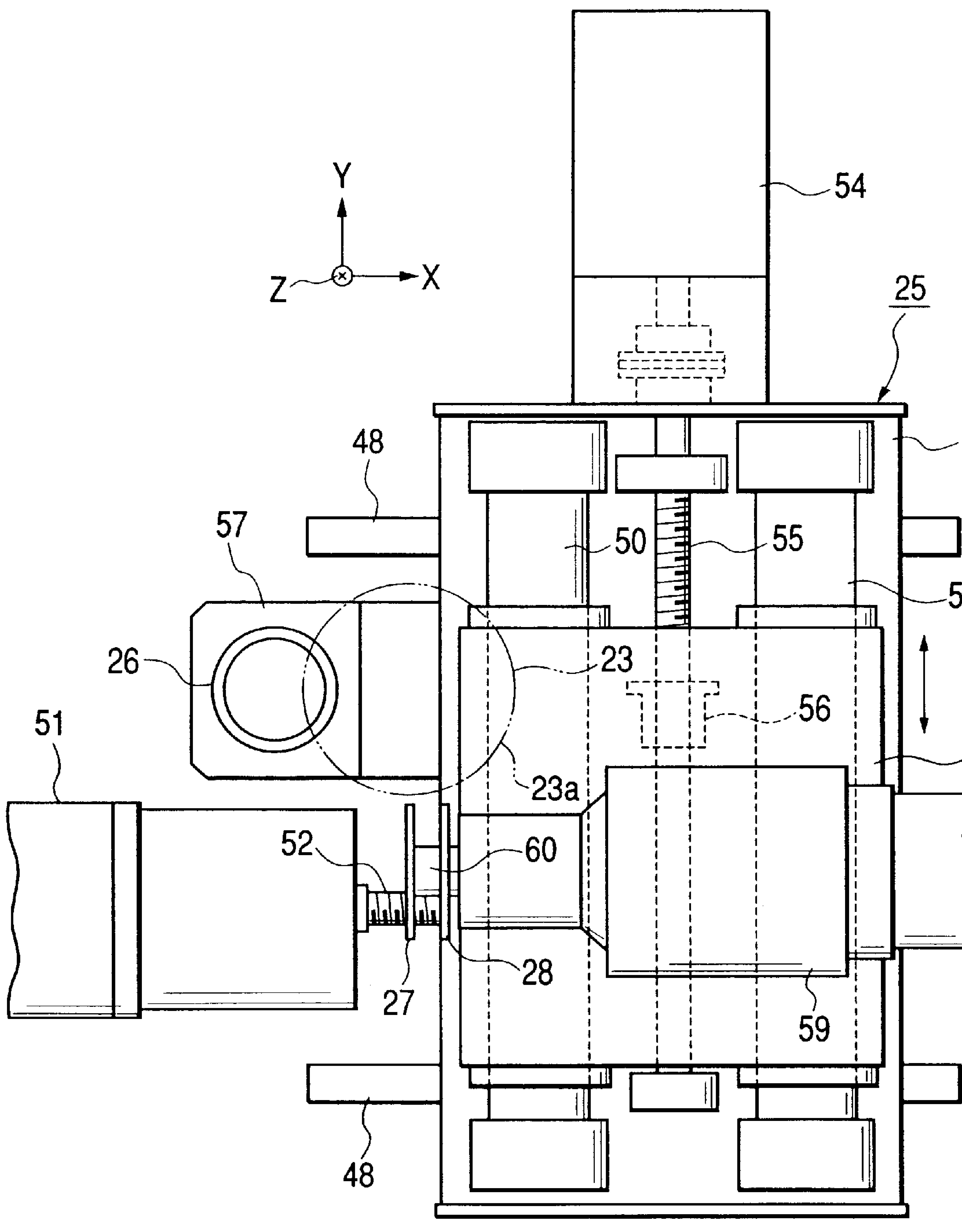

FIG. 3

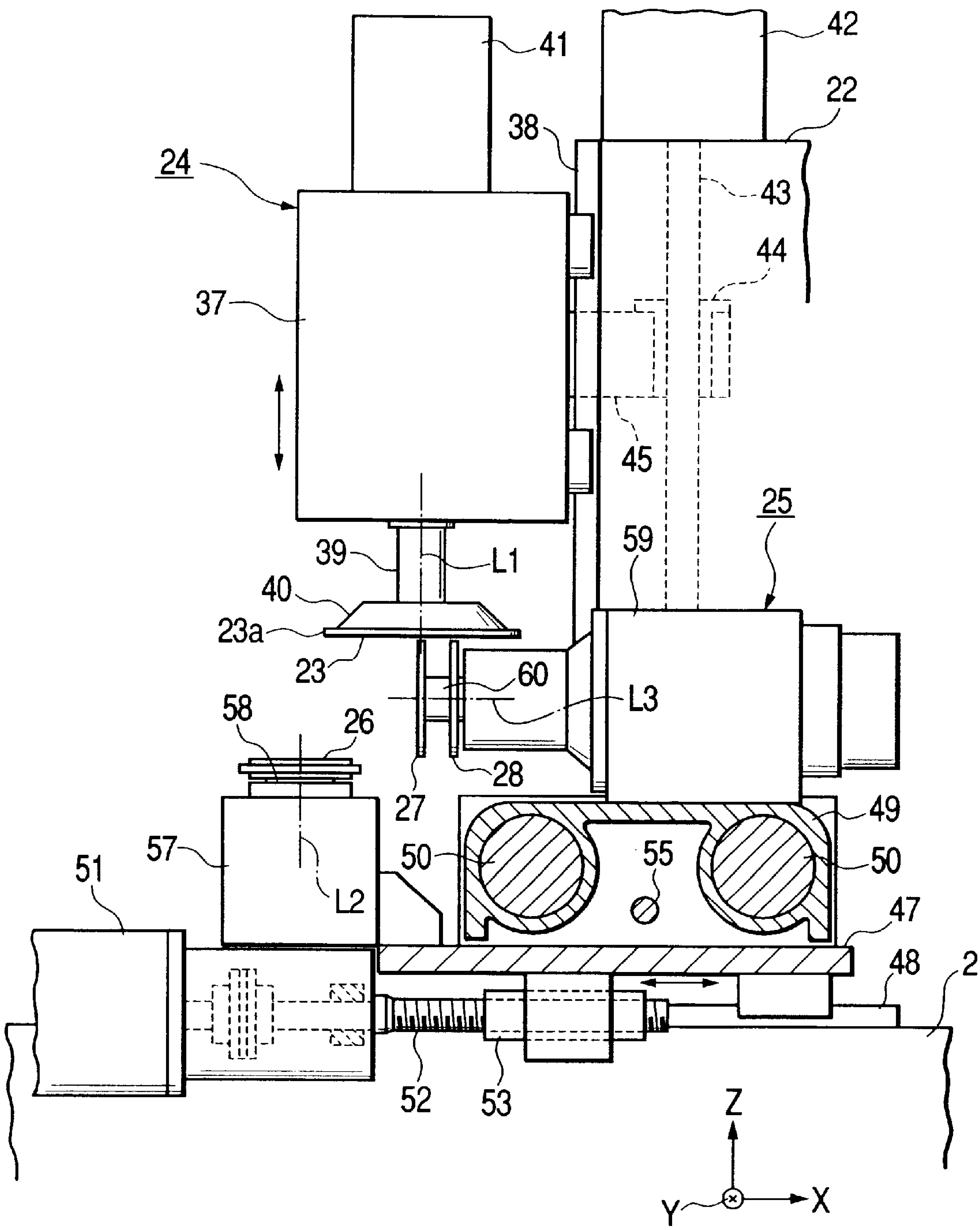

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FIG. 4A

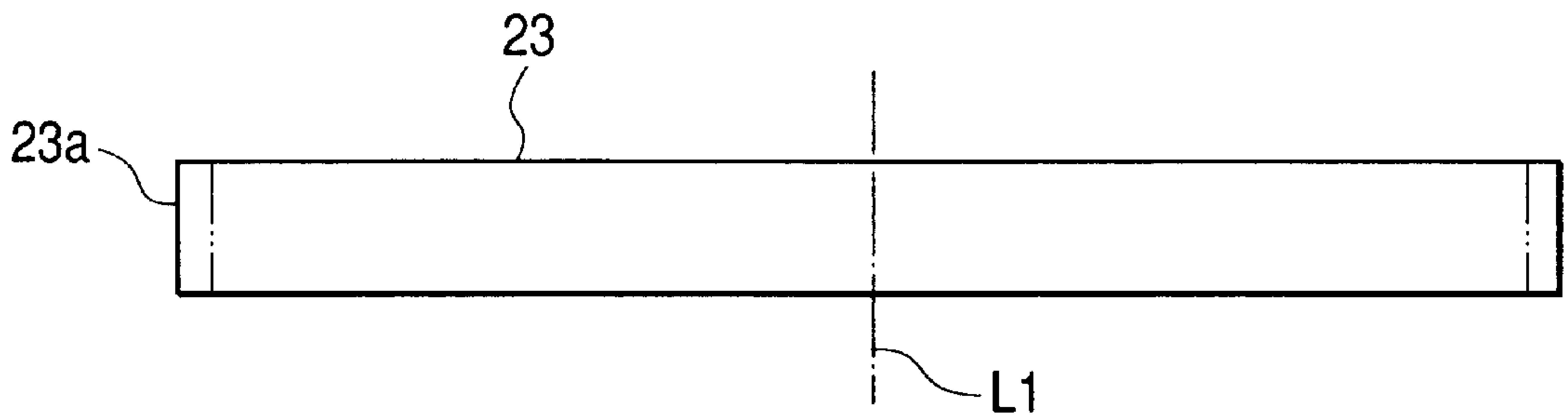

FIG. 4B

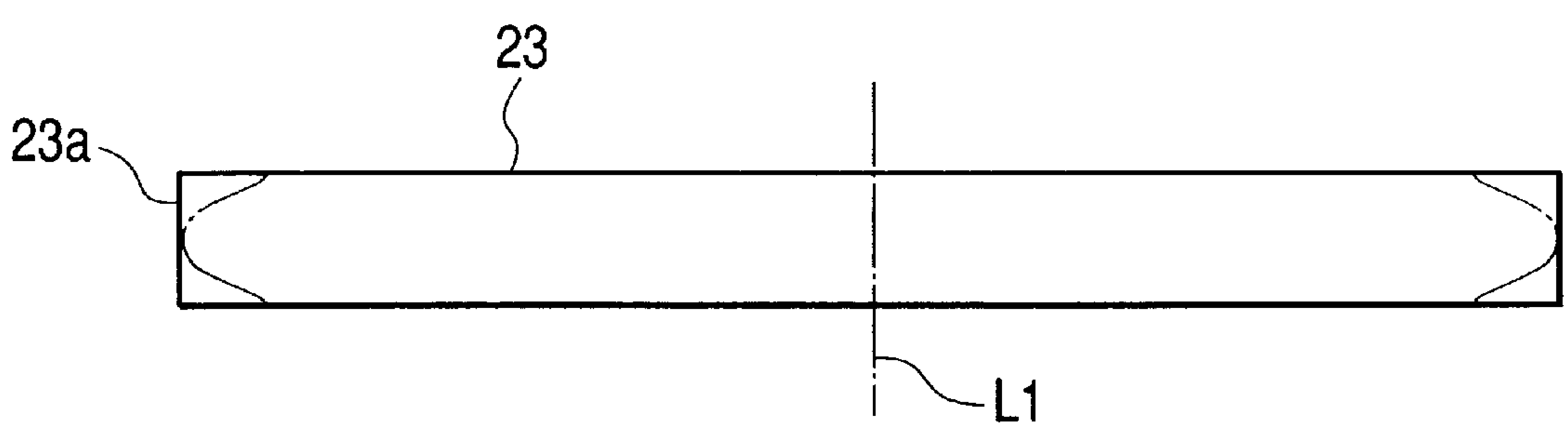

FIG. 4C

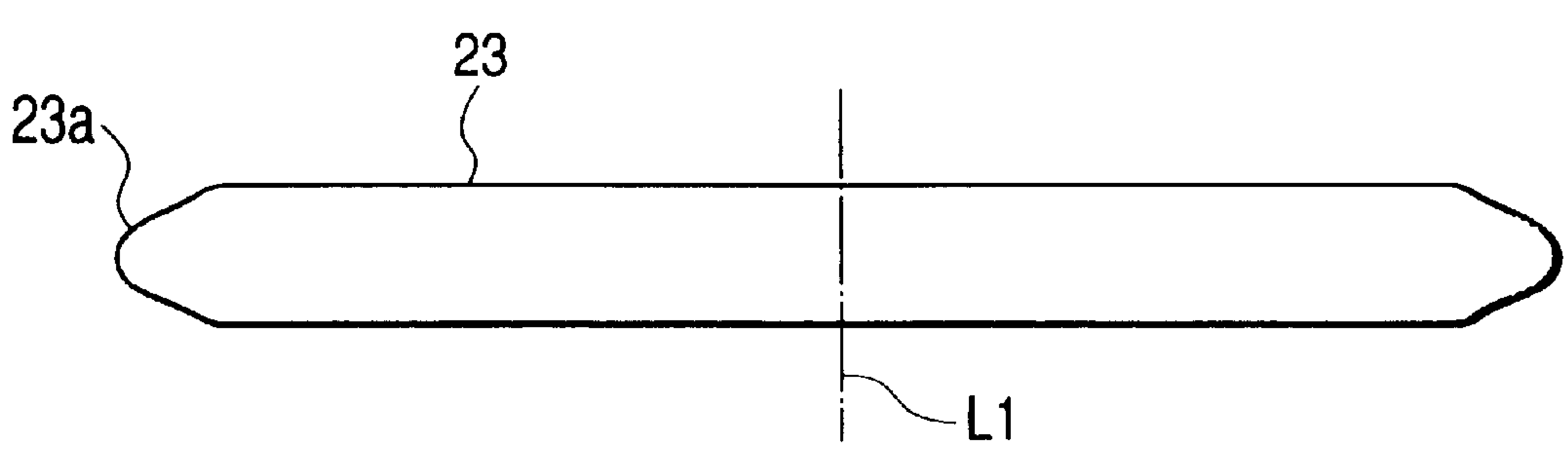

FIG. 5A

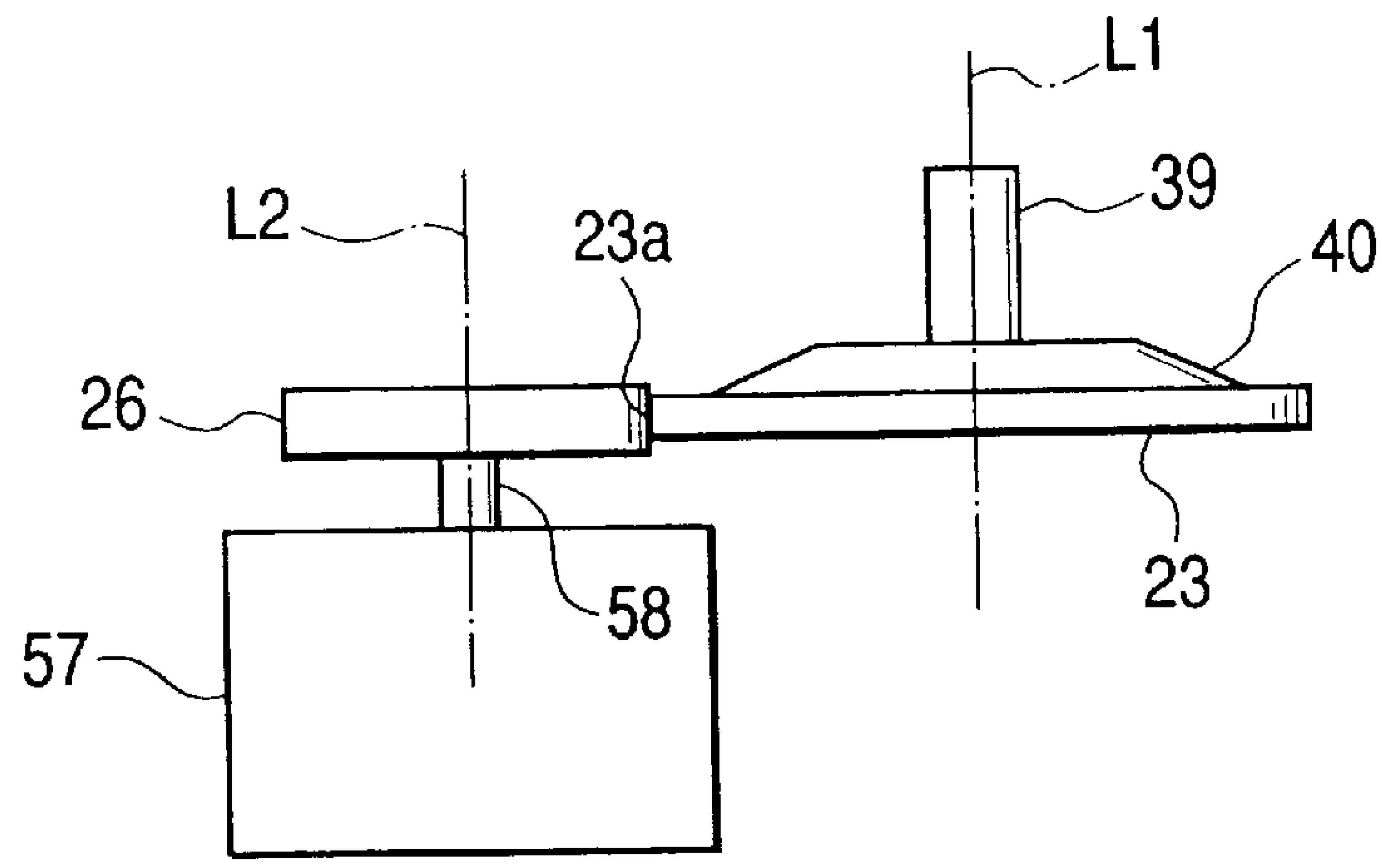

FIG. 5B

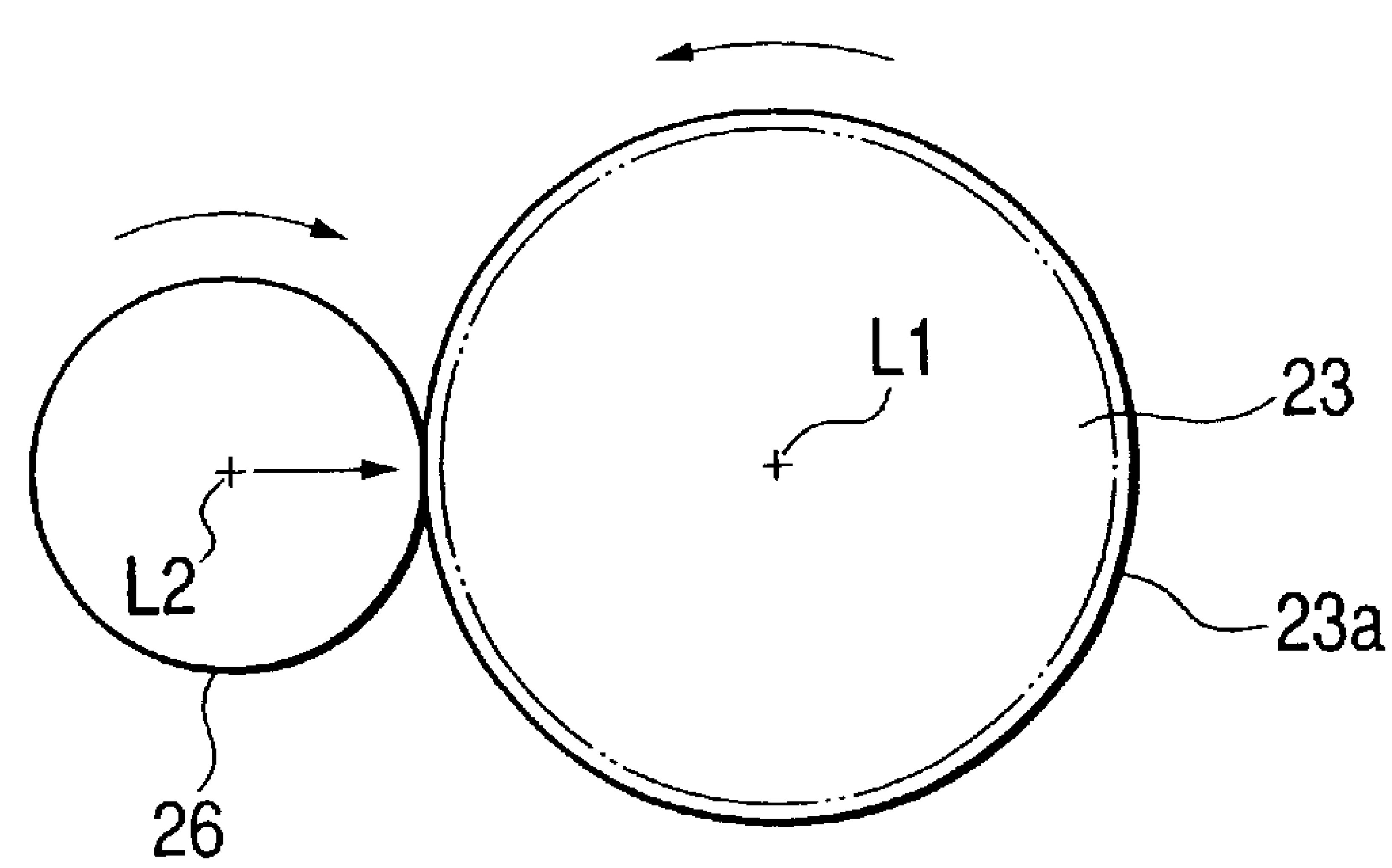

FIG. 5C

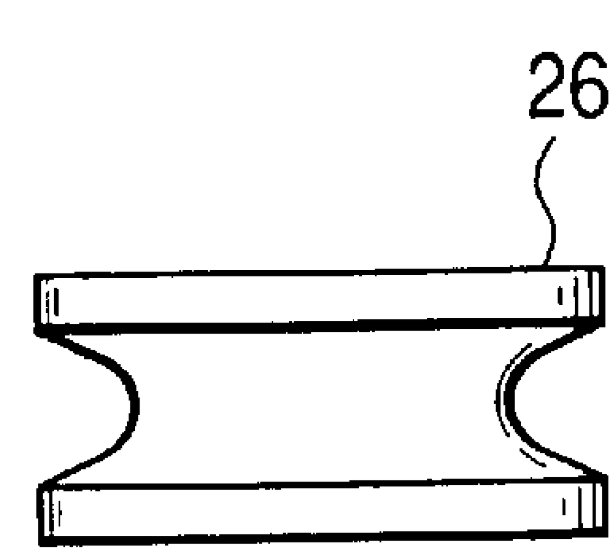

FIG. 6A

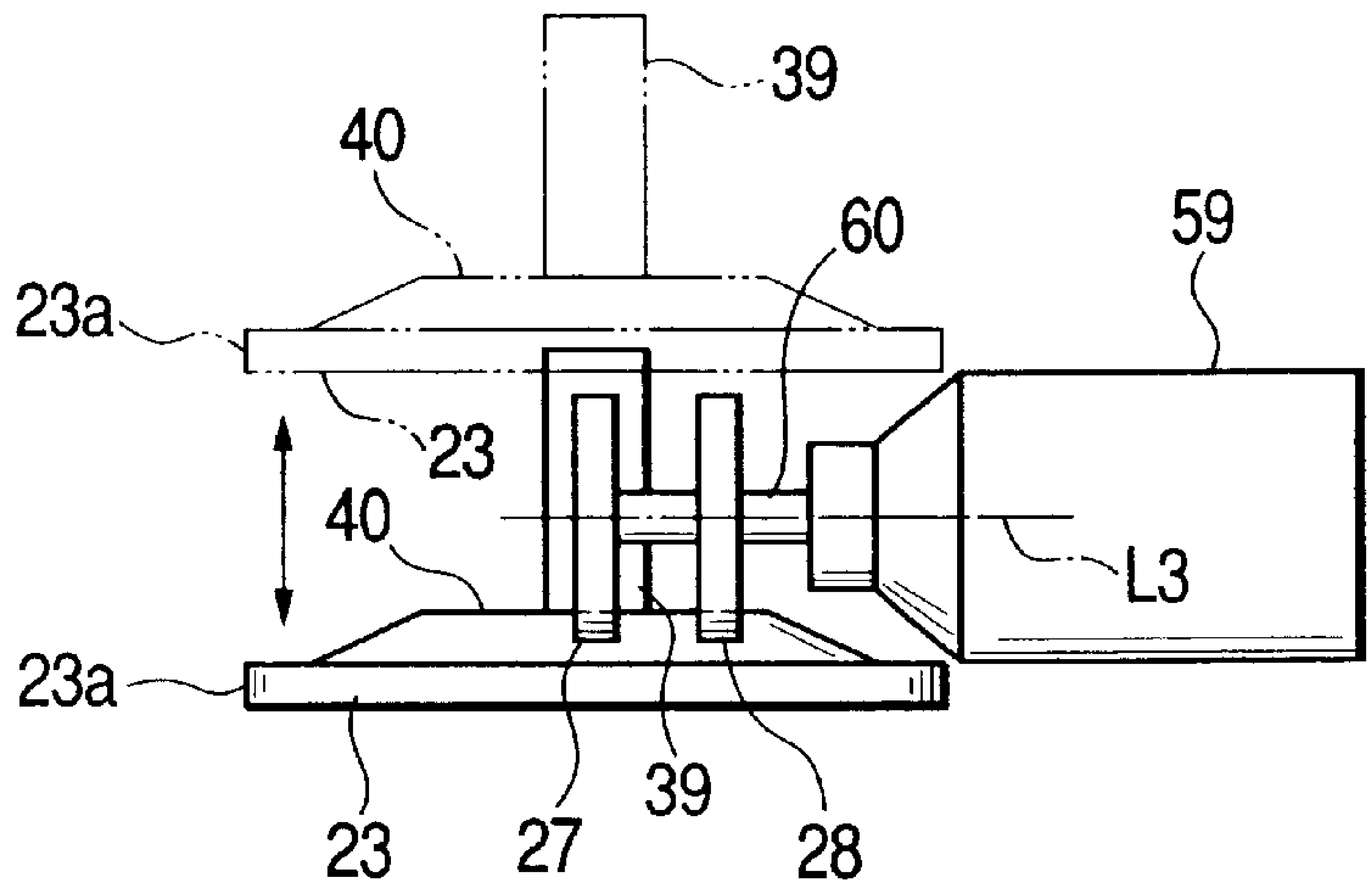

FIG. 6B

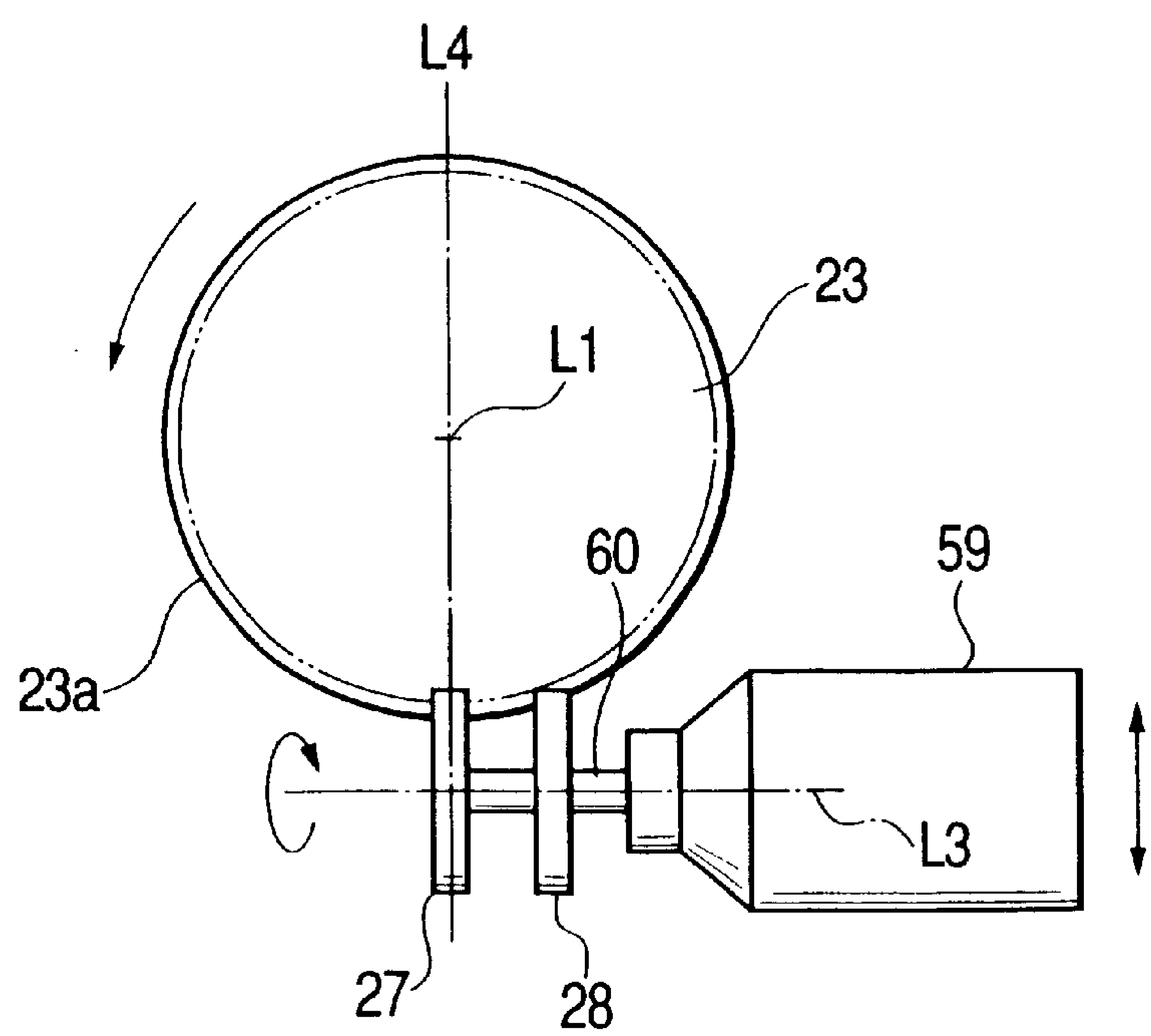

FIG. 7

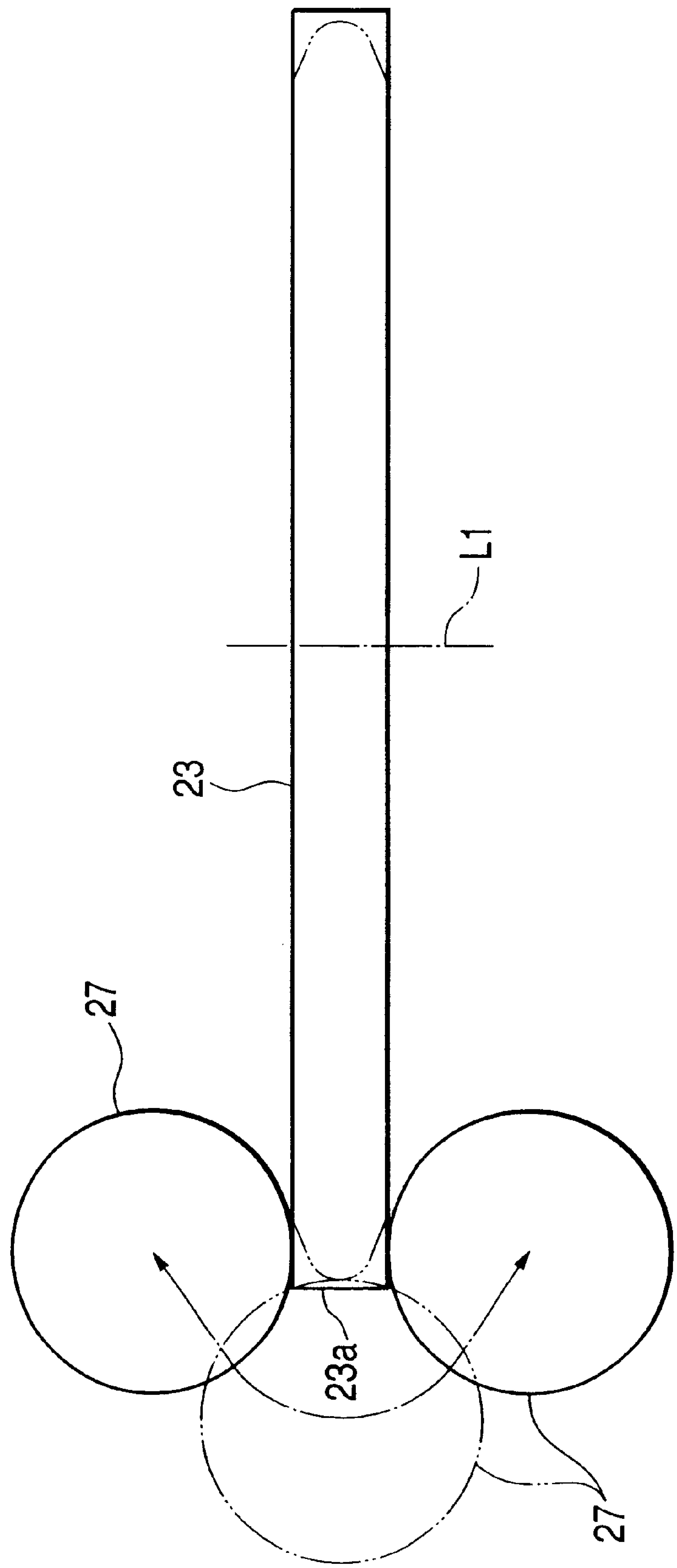

FIG. 8A

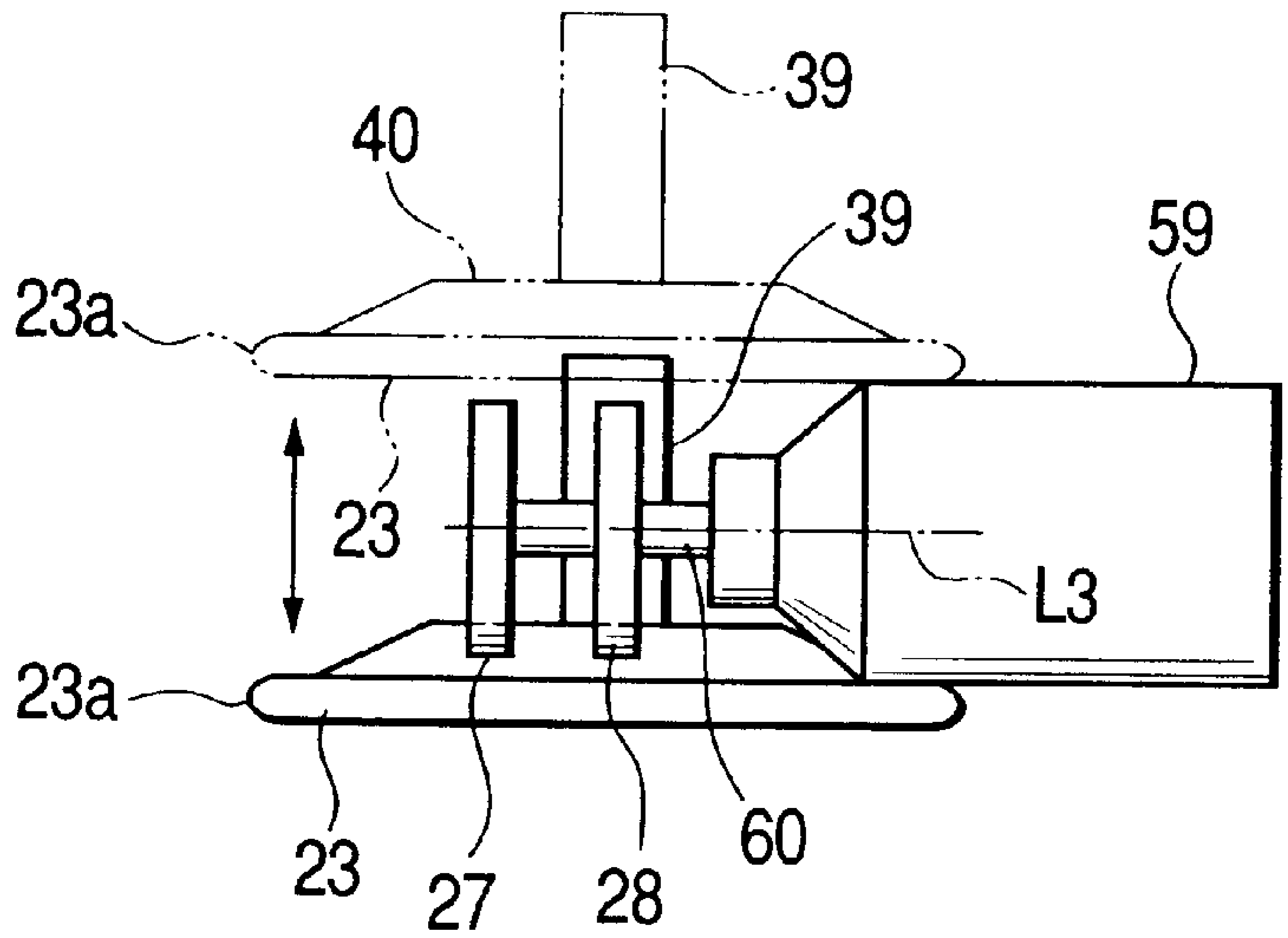

FIG. 8B

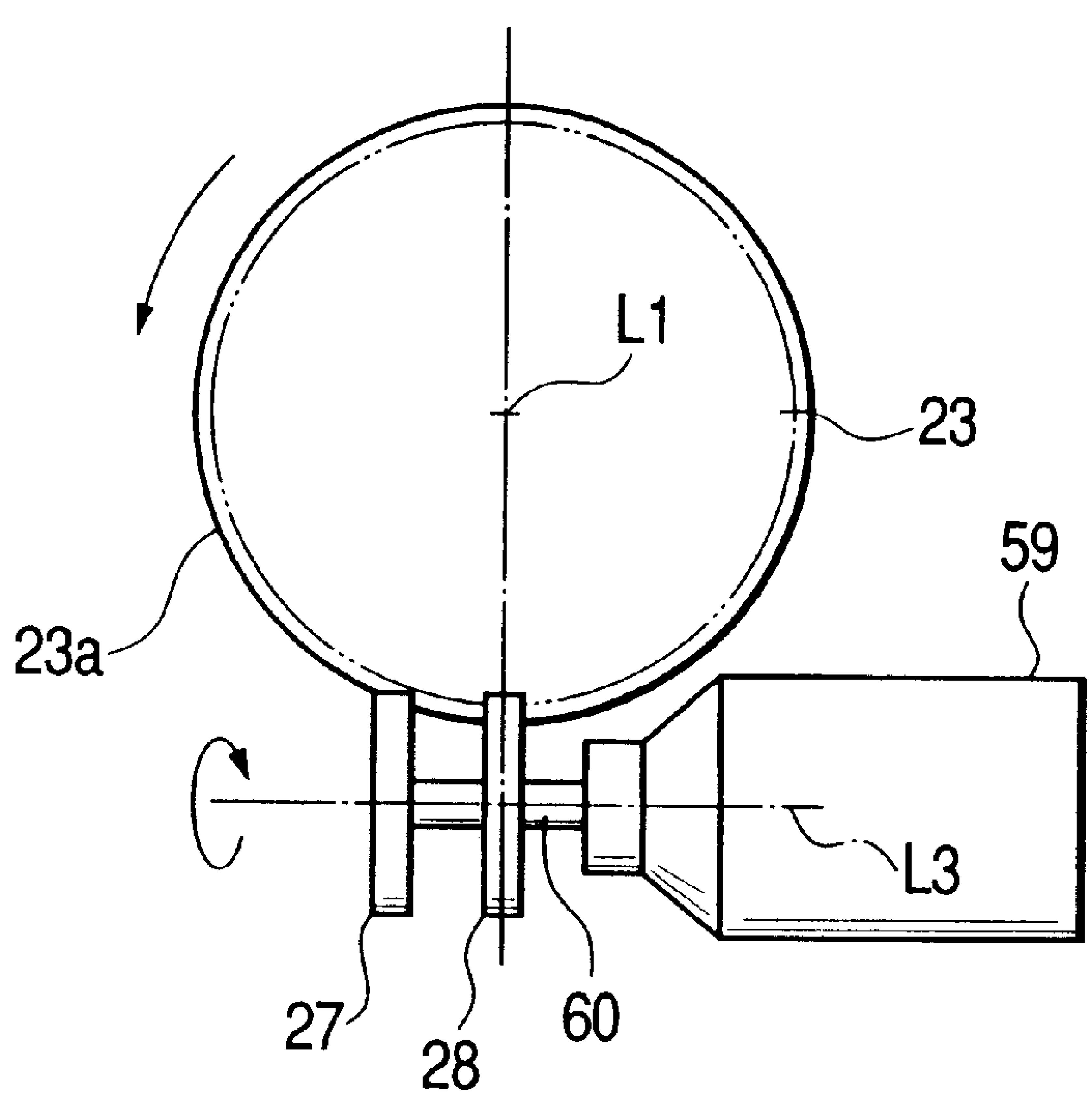

FIG. 9A

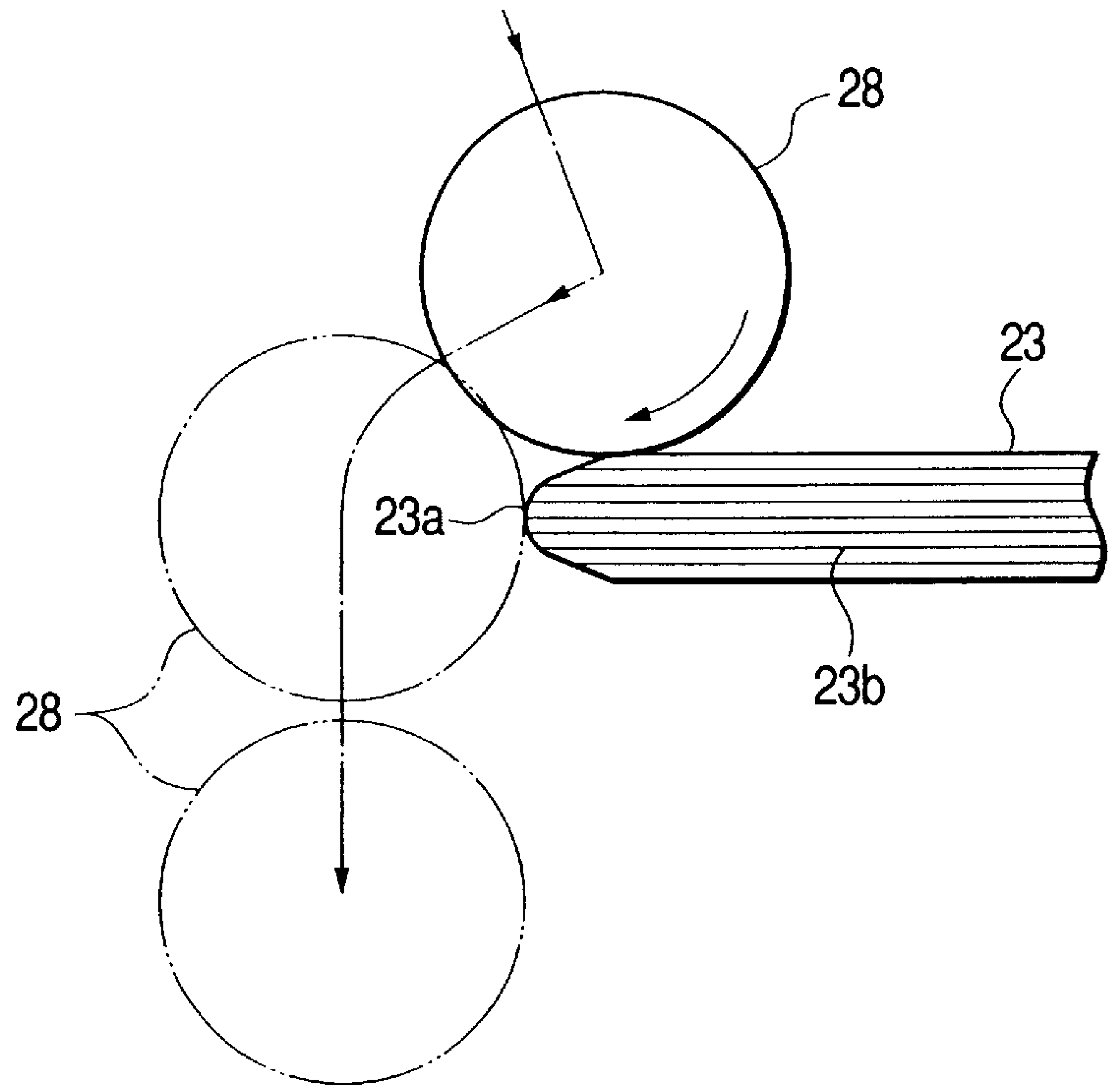

FIG. 9B

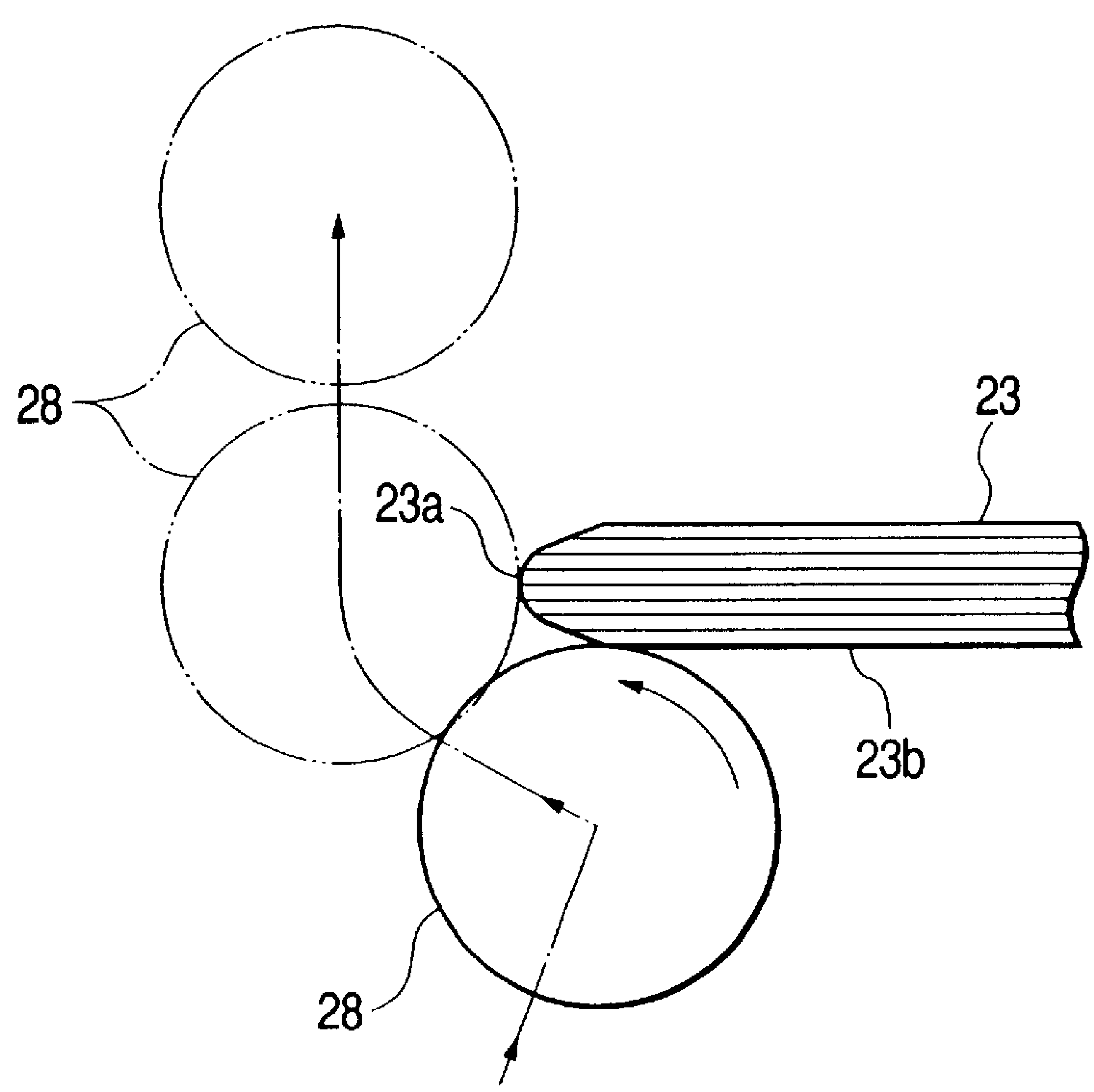

FIG. 10

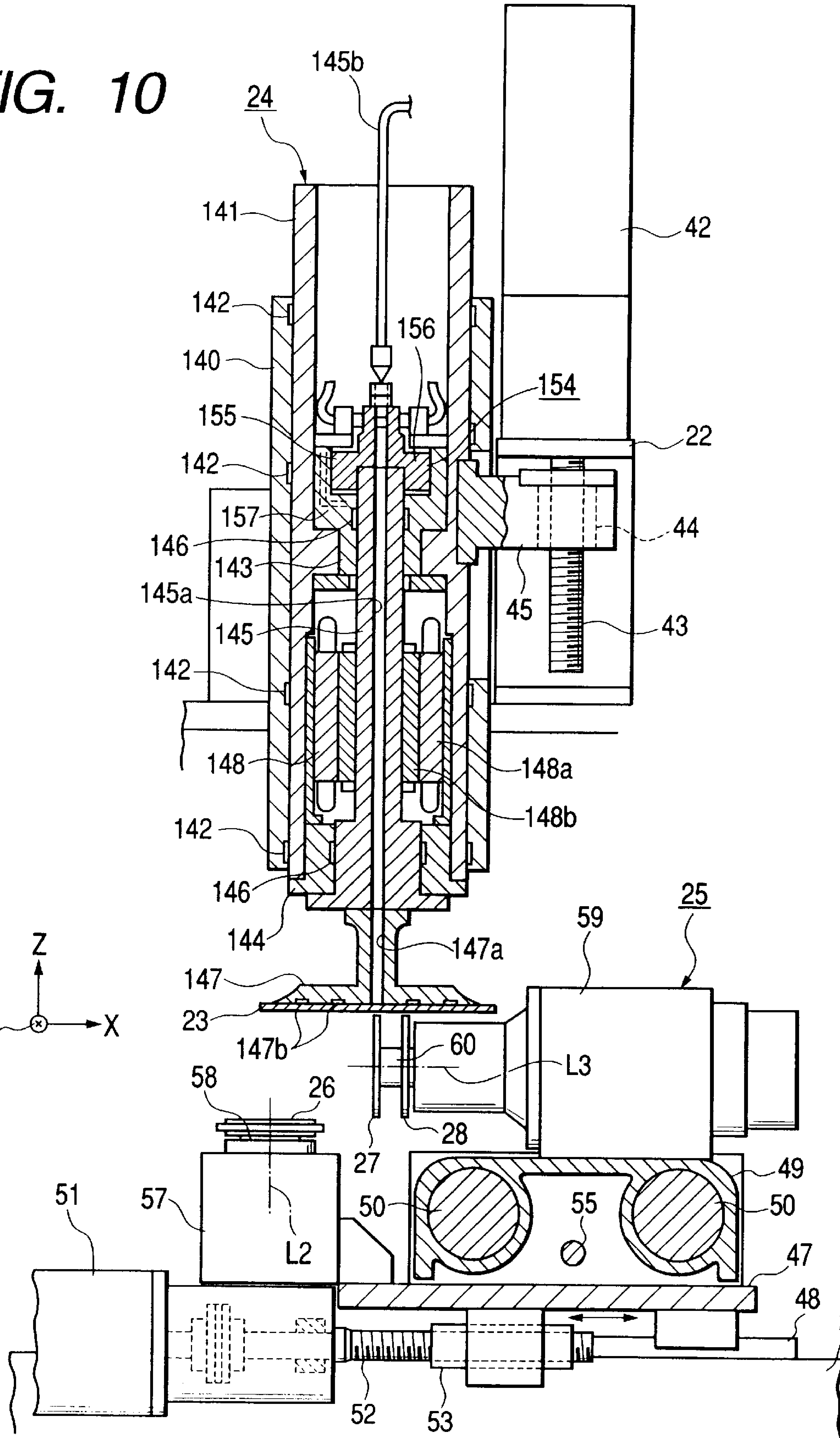
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FIG. 11

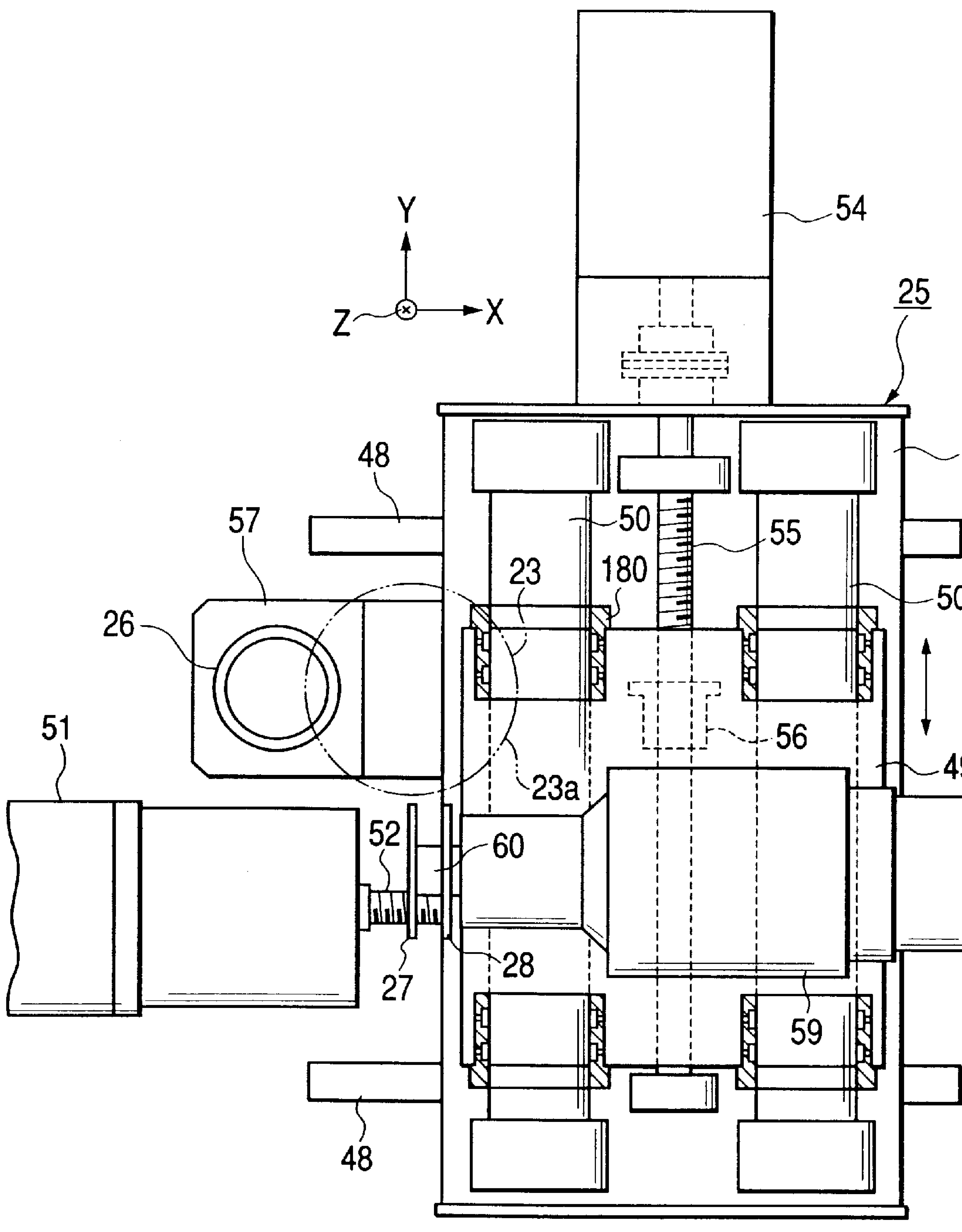


FIG. 12A

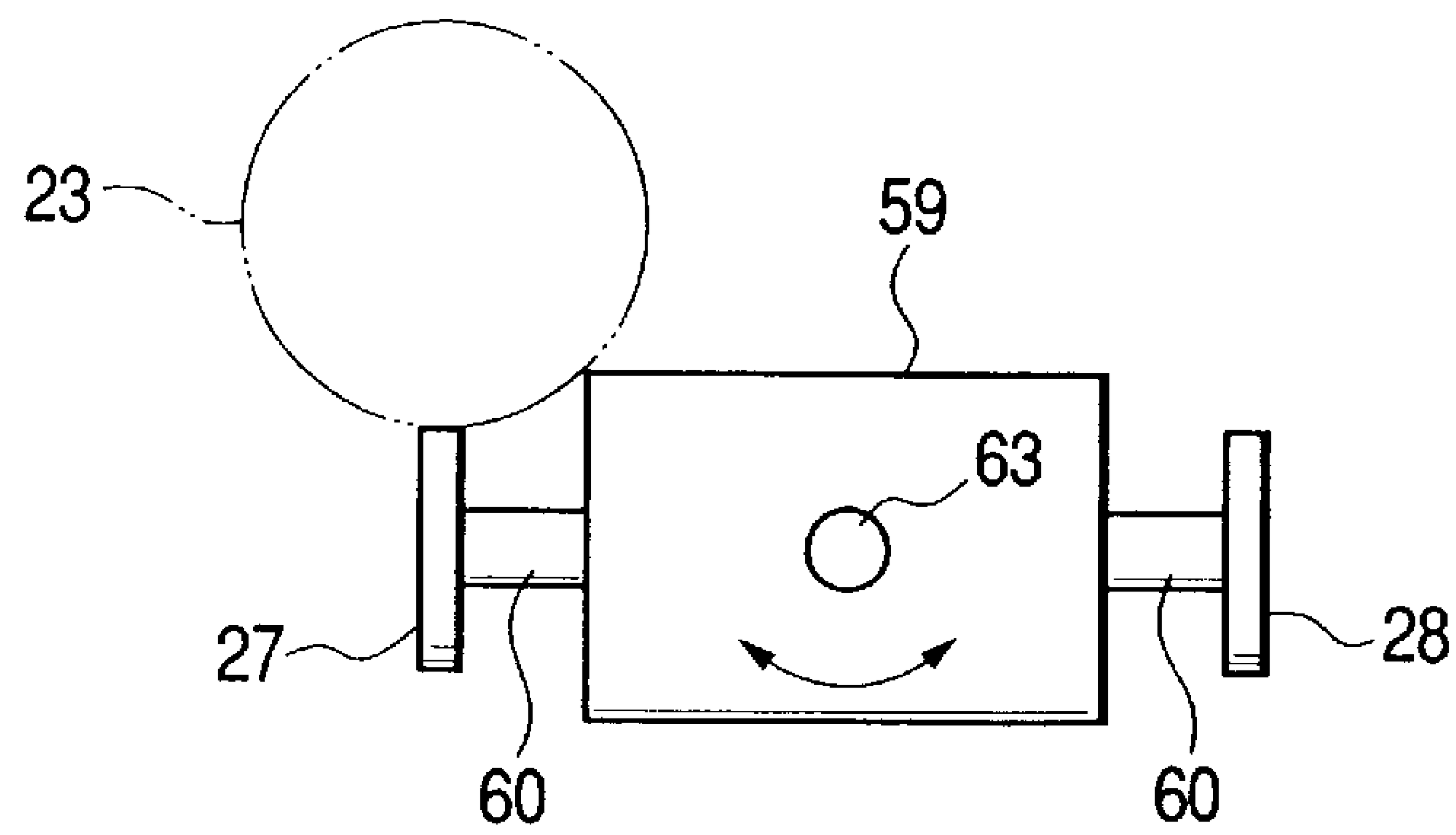


FIG. 12B

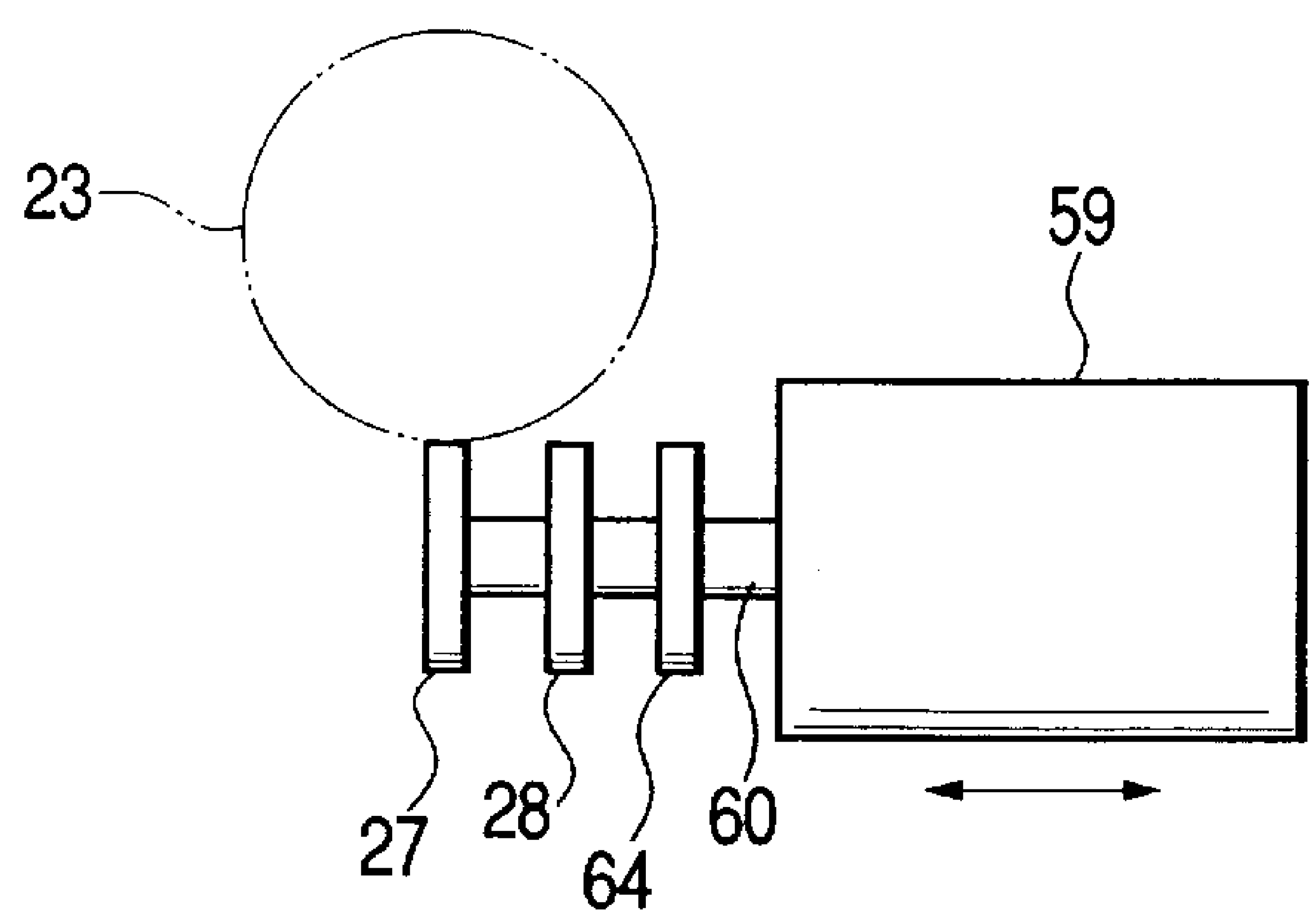


FIG. 12C

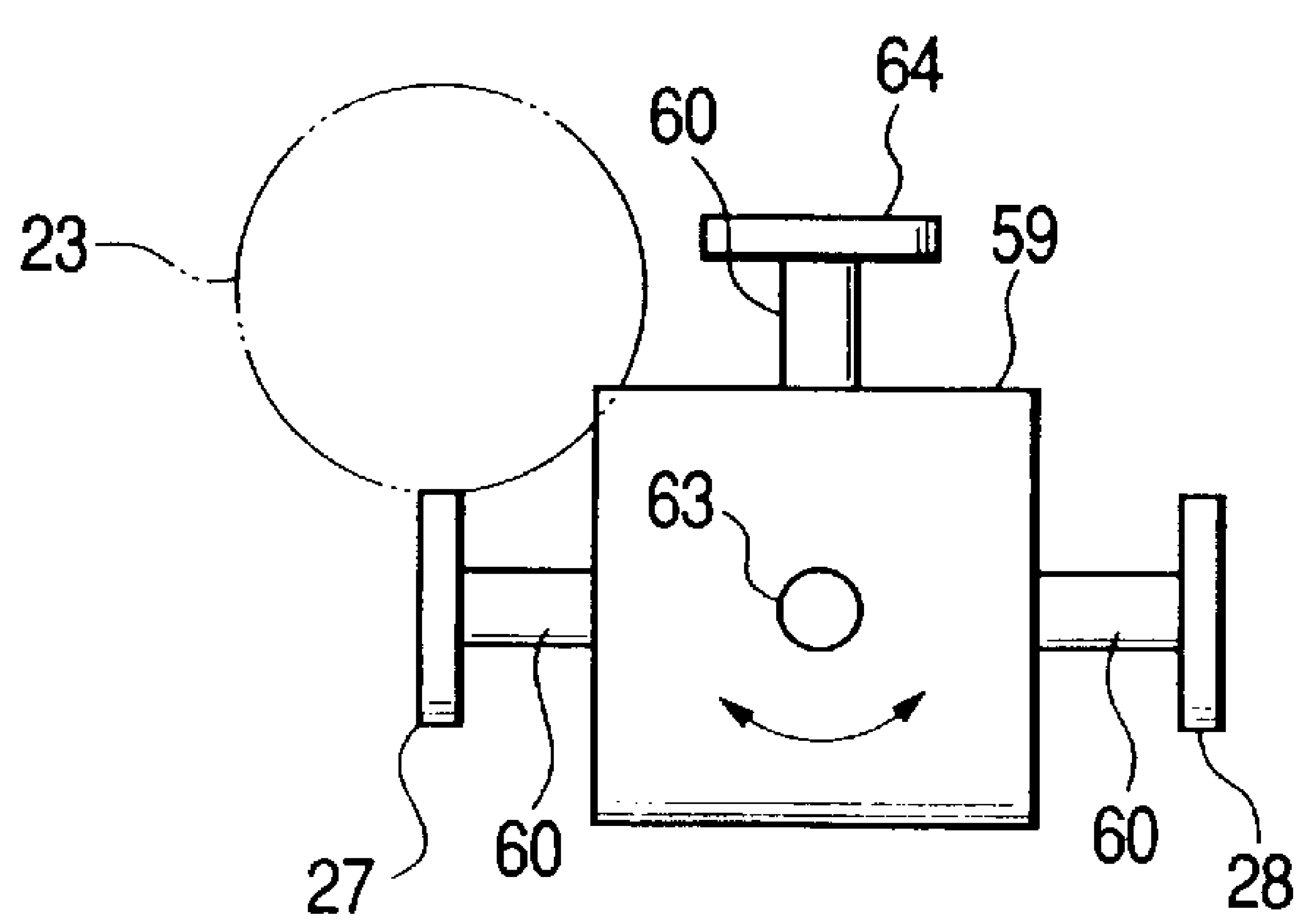


FIG. 13

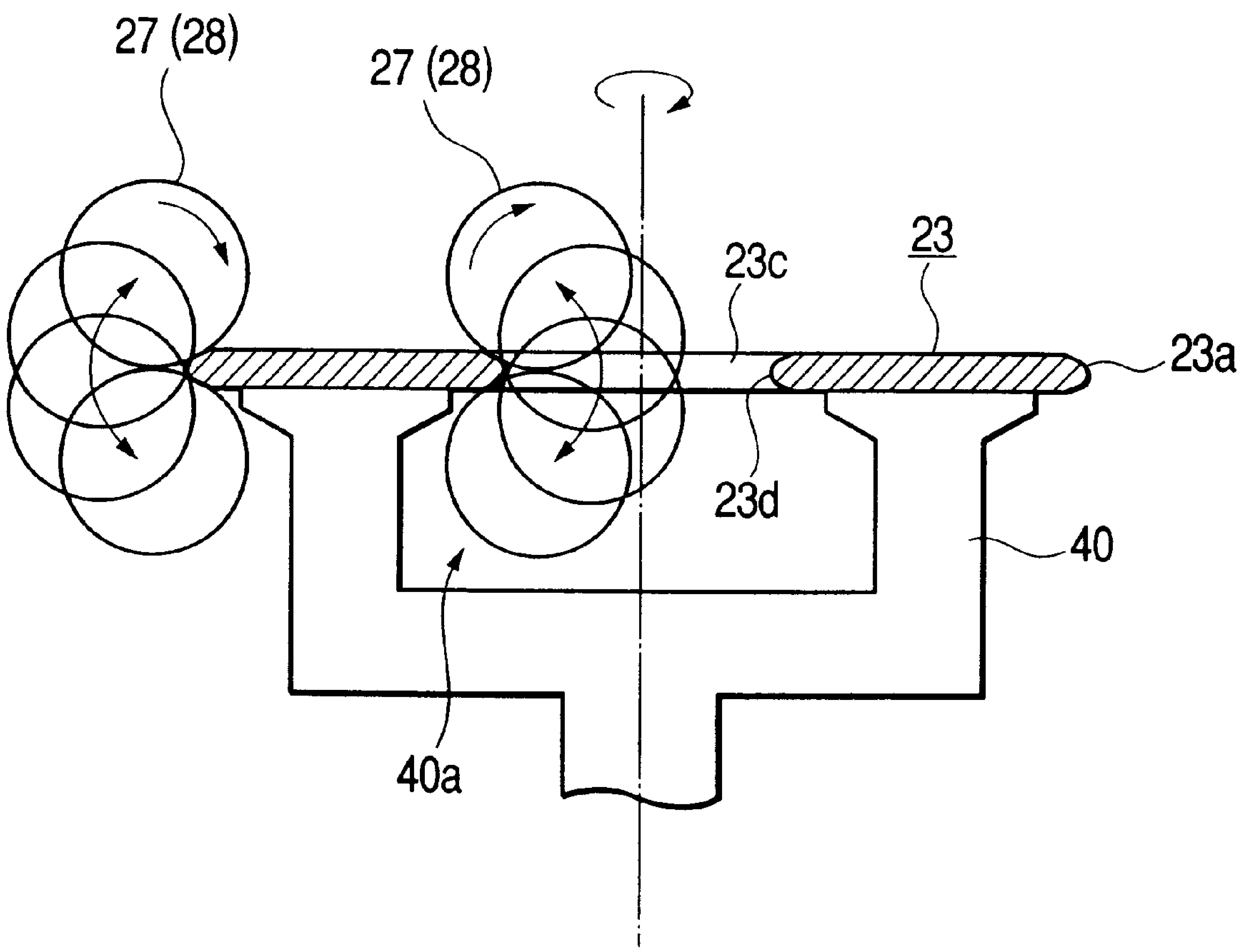
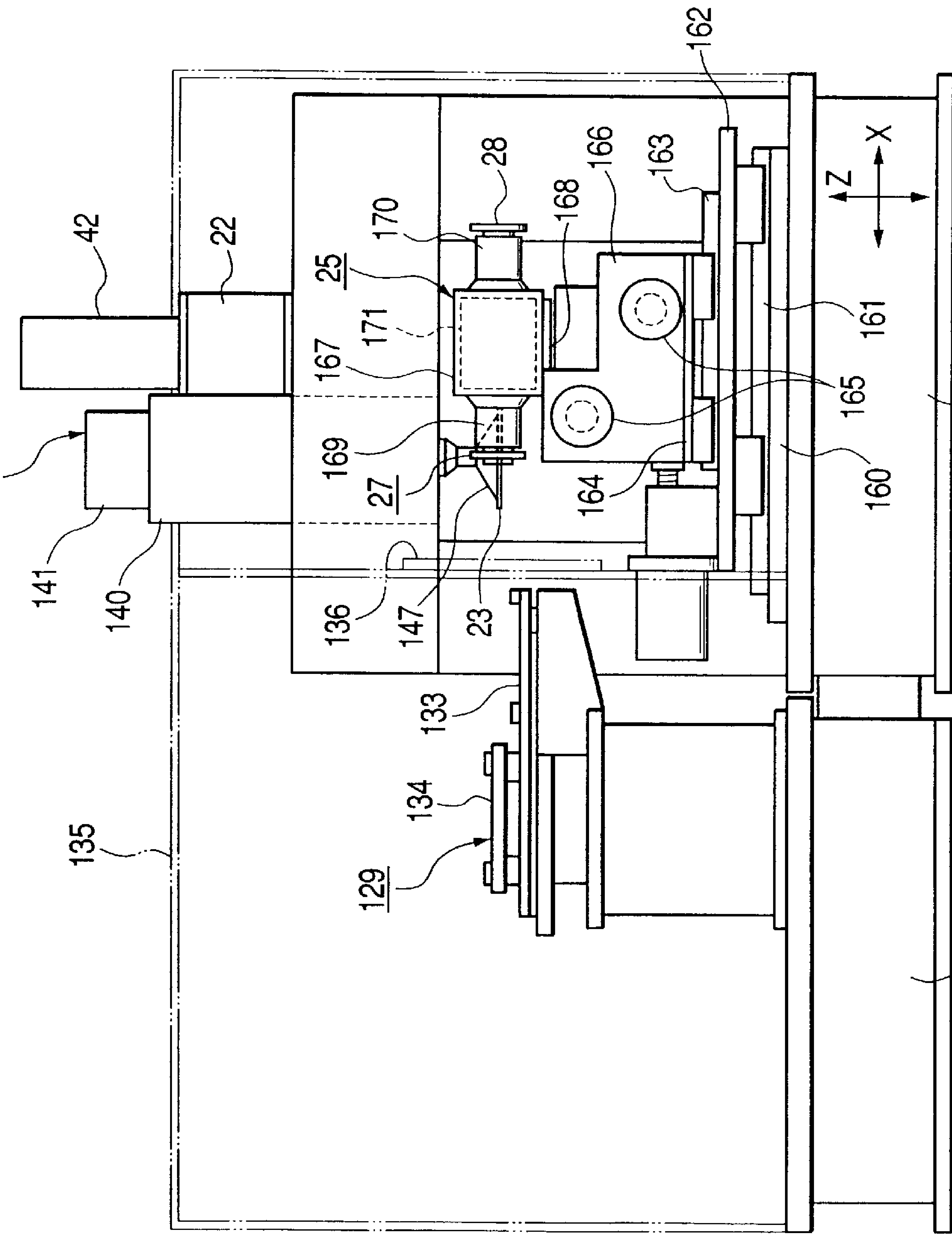


FIG. 14



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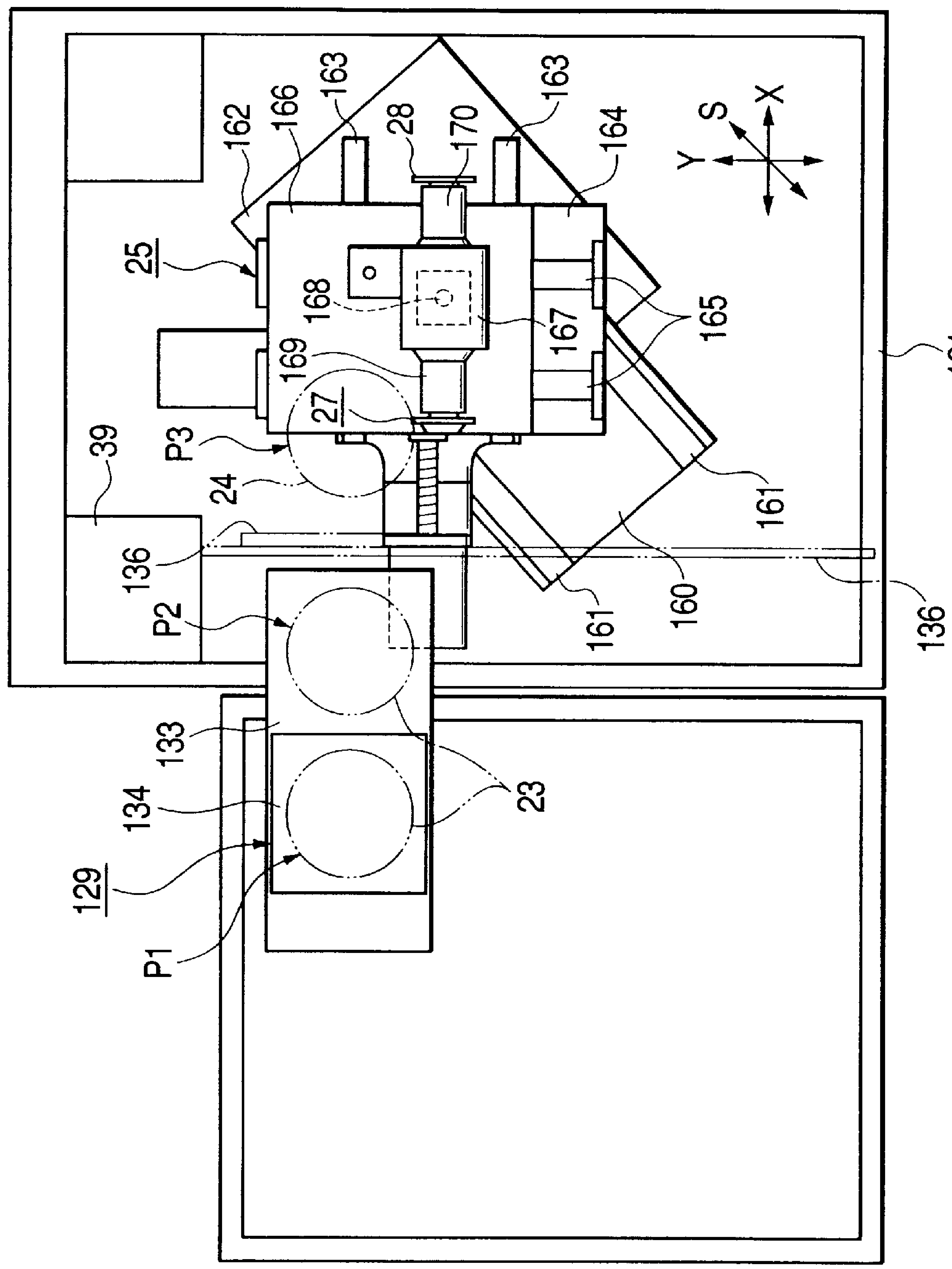
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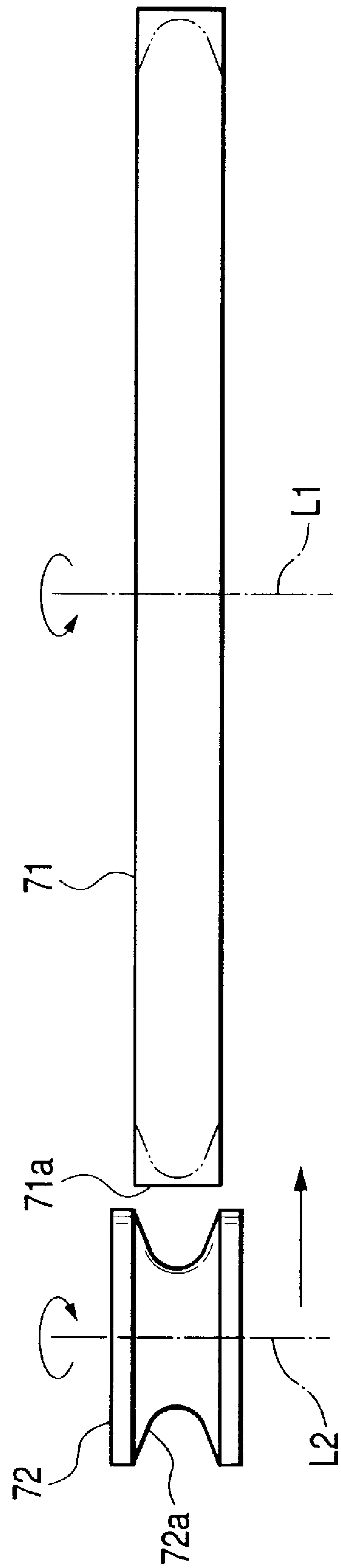
FIG. 15

FIG. 16



METHOD AND APPARATUS FOR GRINDING A WORKPIECE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and an apparatus for grinding a workpiece, specifically, for grinding an outer peripheral edge of a workpiece formed of a circular thin plate such as a semiconductor wafer.

2. Description of the Related Art

Conventionally, in a case where this type of workpiece formed of a circular thin plate is ground, a grinding method such as the one shown in FIG. **16** has been adopted. Namely, in this conventional method, a workpiece **71** is rotated about its center as an axis L**1**, and a forming grinding wheel **72** is moved so as to be fed toward an outer peripheral edge portion **71***a* of the workpiece **71** while being rotated about an axis L**2** which is parallel to the central axis L**1** of the workpiece **71**. As a result, the outer peripheral edge portion **71***a* of the workpiece **71** is ground by a recessed wheel surface **72***a* of the outer periphery of the forming grinding wheel **72**.

However, with this conventional method of grinding a workpiece, since the outer peripheral edge portion **71***a* of the workpiece **71** is arranged to be ground at one time by the recessed wheel surface **72***a* of the forming grinding wheel **72**, the recessed wheel surface **72***a* of the forming grinding wheel **72** has been liable to become worn, and the deformation of its profile has been liable to occur as a result. For this reason, particularly in finishing, it is extremely difficult to maintain constant the machining accuracy of the profiles of the outer peripheral edge portions **71***a* of a multiplicity of workpieces **71** by a single forming grinding wheel **72**, and it has been necessary to replace the forming grinding wheel **72** frequently, so that there have been problems in terms of the machining accuracy and machining cost.

SUMMARY OF THE INVENTION

The invention has been devised in light of the above-described problems which are present in the conventional art. Its object is to provide a method of and an apparatus for grinding a workpiece which make it possible to grind outer peripheral edge portions of workpieces while maintaining constant machined shape accuracy, and which make it unnecessary to replace the grinding wheel frequently.

To solve the above object, according to a first aspect of the invention, there is provided a method of grinding a workpiece, a workpiece formed of a circular thin plate is rotated about its center as an axis, and each of the disk-shaped rotating grinding wheels, while being rotated about an axis substantially parallel to the plane of the workpiece, is made to undergo relative feeding movement on both obverse and reverse surf ace sides of the workpiece along the outer peripheral edge portion of the workpiece. Consequently, the outer peripheral edge portion of the workpiece is ground by the outer peripheral wheel surface of each of the rotating grinding wheels.

In this connection, the wording “the rotating grinding wheel” includes a pad, and the wording “grinding” includes polishing. And, these wordings are used as well in the below description.

In addition, the above relative feeding movement is performed such that the grinding wheel continuously moves on at least one part of a predetermined configuration of the edge portion to be ground along a thickness direction of the workpiece.

For this reason, as compared with the conventional grinding method in which the outer peripheral edge portion of the workpiece is ground by a forming grinding wheel, the profile of the wheel surface of each of the rotating grinding wheels is less prone to deformation, so that it be comes unnecessary to replace the rotating grinding wheels frequently. Accordingly, it is possible to reduce the material cost of the rotating grinding wheels, and hence the machining cost. Furthermore, since the profile of the wheel surface of each of the rotating grinding wheels is less prone to deformation, the outer peripheral edge portions of the workpieces can be ground into constant machined shapes with high accuracy.

In addition, the edge portion of the workpiece can be finished into an arbitrary shape by the same grinding wheels through the relative feeding control of the workpiece and the rotating grinding wheels.

In the method of grinding a workpiece according to the invention, the axis of the rotating grinding wheels is disposed in such a manner as to be perpendicular to the radial direction of the workpiece. For this reason, the rotation of the workpiece is effected so as to traverse the outer peripheral surface of each of the rotating grinding wheels. In other words, the workpiece undergoes relative movement in the widthwise direction of the rotating grinding wheels. Accordingly, it becomes possible to effectively grind all over the outer peripheral edge portion of the workpiece by making effective use of the overall width of the outer peripheral wheel surfaces of the rotating grinding wheels.

In the method of grinding a workpiece according to the invention, the rotating grinding wheels consist of the two grinding wheels for rough grinding and finish grinding, and rough grinding and finish grinding are performed by the grinding wheels, respectively. For this reason, the grinding of the outer peripheral edge portion of the workpiece can be effected separately for rough grinding and finish grinding and continuously and efficiently with high accuracy.

In the method of grinding a workpiece according to the invention, the rough grinding and finish grinding of the outer peripheral edge portion of the workpiece are performed by the same station. For this reason, it becomes unnecessary to transport the workpiece into another station or shift the holding of the workpiece, and it is possible to continuously perform rough grinding and finish grinding for the outer peripheral edge portion in the state of being disposed in the same station. Hence, it is possible to maintain the positional accuracy of the workpiece and improve the operating efficiency. Further, stations for rough grinding and finish grinding need not be provided separately, the arrangement of the grinding apparatus can be simplified, and the grinding apparatus can be made compact.

In the method of grinding a workpiece according to the invention, a rotating grinding wheel which is formed by binding the grains of silicon dioxide into fixed abrasive grains is used as the rotating grinding wheel for finishing. For this reason, the outer peripheral edge portion of the workpiece can be ground with good finish-ground surface roughness by virtue of the chemical action based on the reducing action of silicon dioxide.

In the method of grinding a workpiece according to the invention, after the outer peripheral edge portion of the workpiece is subjected to rough grinding and finish grinding by using the rotating grinding wheels; final finishing is performed by using the disk-shaped polishing pad and slurry. For this reason, the relatively soft polishing pad are applied, and the slurry always cools the machined portion of the workpiece. Hence, it is possible to further enhance the ground surface roughness of the outer peripheral edge portion of the workpiece and effect super-finish grinding.

In the method of grinding a workpiece according to the invention, an outer peripheral edge portion of the workpiece is ground.

Accordingly, it is possible to obtain the aforementioned operational advantages in the grinding of the outer peripheral edge portion.

In the method of grinding a workpiece according to the invention, an inner peripheral edge portion of the workpiece having a circular hole in its center is ground.

Accordingly, it is possible to obtain the aforementioned operational advantages in the grinding of the inner peripheral edge portion.

In the method of grinding a workpiece according to the invention, a rotating grinding wheel for cylindrical grinding is rotated about an axis parallel to the central axis of the workpiece in a process preceding the grinding by the disk-shaped rotating grinding wheel, so as to effect the rough cutting of the edge portion of the workpiece by cylindrical grinding.

Accordingly, since rough cutting by cylindrical grinding, which makes it possible to secure a large amount of grinding per unit time in a preceding process, is adopted, the grinding can be performed efficiently. Moreover, since this cylindrical grinding is rough cutting, even if the profile of the outer peripheral surface of the rotating grinding wheel for cylindrical grinding is slightly broken, machining accuracy remains substantially unaffected.

In this connection, the rotating grinding wheel for cylindrical grinding includes a forming grinding wheel.

In a second aspect according to the invention, there is provided a method of grinding a workpiece, characterized in that a workpiece formed of a circular thin plate is rotated about its center as an axis, that a rotating grinding wheel for cylindrical grinding is concurrently rotated about an axis parallel to a central axis of the workpiece so as to effect the rough cutting of a edge portion of the workpiece by cylindrical grinding, and that a disk-shaped rotating grinding wheel, while being rotated about an axis extending in a direction substantially parallel to a plane of the workpiece and perpendicular to a radial direction of the workpiece, is subsequently made to undergo relative feeding movement on both obverse and reverse surface sides of the workpiece along an edge portion of the workpiece, so as to grind the edge portion of the workpiece by an outer peripheral surface of the disk-shaped rotating grinding wheel.

Accordingly, since the edge portion of the workpiece is subjected to rough cutting in advance in the preceding process, the subsequent grinding of the edge portion of the workpiece can be performed efficiently. Furthermore, the wheel surface of the disk-shaped rotating grinding wheel is difficult to be worn, so that it is unnecessary to replace the rotating grinding wheel frequently, and the edge portion of the workpiece can be ground into a constant machined shape with high accuracy.

In the method of grinding a workpiece according to the invention, two grinding wheels including one for rough grinding and another for finish grinding are provided as the disk-shaped rotating grinding wheel, and rough grinding and finish grinding are performed after the rough cutting.

Accordingly, the grinding of the edge portion of the workpiece can be effected efficiently with high accuracy by being divided into rough grinding and finish grinding, and the arrangement of the apparatus can be made simple and compact by the joint use of the machining station.

Furthermore, according to a third aspect of the invention, there is provided an apparatus for grinding a workpiece, characterized by comprising: workpiece holding means for holding a workpiece formed of a circular thin plate and for rotating the workpiece about its own axis; and grinding means having a disk-shaped rotating grinding wheel and for causing the rotating grinding wheel, while being rotated about an axis substantially parallel to a plane of the workpiece, to undergo relative feeding movement on both obverse and reverse surface sides of the workpiece along an edge portion of the workpiece, so as to grind the edge portion of the workpiece.

Accordingly, it is possible to realize an apparatus in which the wheel surface of the grinding wheel is difficult to be worn, it is unnecessary to replace the grinding wheel frequently, and the outer peripheral edge portion or the inner peripheral edge portion of the workpiece can be ground into a constant machined shape with high accuracy, as described above.

In addition, the edges of the workpieces can be finished to arbitrary shapes by the same grinding wheel through the relative feed control of the workpiece and the rotating grinding wheel.

In the apparatus for grinding the workpiece according to the invention, a guide mechanism for guiding the relative movement of the workpiece and the rotating grinding wheel for performing the processing is formed by a hydrostatic bearing.

Accordingly, when the grinding wheel and the workpiece are relatively moved, for instance, in a Z direction along the rotational axis of the workpiece and in a Y direction perpendicular thereto, the relative movement of the grinding wheel and the workpiece is effected smoothly by the guide mechanism including the hydrostatic bearing. Accordingly, it is possible to prevent vibrations from occurring during the relative movement of the grinding wheel and the workpiece, thereby making it possible to improve the processing accuracy of the ground surface of the workpiece.

Further, according to a fourth aspect of the invention, the rotating grinding wheel, while being rotated in one direction, is moved to be fed toward the edge portion of the workpiece starting with its obverse surface side and then toward its tip side, to thereby grind the obverse surface side of the edge portion, and, subsequently, the rotating grinding wheel, while being rotated in the opposite direction, is moved to be fed toward the edge portion of the workpiece starting with its reverse surface side and then toward its tip side, to thereby grind the reverse surface side of the edge portion.

In accordance with this grinding method, since grinding is performed by bisecting an allowance for the obverse and reverse surfaces of the edge portion of the workpiece in such a manner as to depict symmetrical loci of movement on the obverse surface side and the reverse surface side, grinding can be performed by the same change of the grinding conditions for both the obverse and reverse surface sides in correspondence with the angle of the crystalline face appearing at the edge portion, and it is possible to prevent the occurrence of variations in the roughness of the ground surface between the obverse surface side and the reverse surface side of the edge portion. Hence, the edge portion of the workpiece can be ground uniform ground surface roughness with high accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially fragmentary plan view illustrating an embodiment of a grinding apparatus;

FIG. **2** is an enlarged plan view of an essential portion and illustrates in enlarged for a portion of the grinding apparatus shown in FIG. **1**;

FIG. **3** is an enlarged cross-sectional view of the essential portion of the grinding apparatus shown in FIG. **1**;

FIGS. **4**A to **4**C are explanatory views illustrating the method of grinding an outer peripheral edge portion in the order of processes;

FIGS. **5**A and **5**B are a front elevational view and a plan view illustrating a rough cutting process;

FIG. **5***c* is a side view illustrating a modification of a rotating grinding wheel for the rough cutting process;

FIGS. **6**A an **6**B are a front elevational view and a plan view illustrating a rough grinding process;

FIG. **7** is a side elevational view illustrating in enlarged form the rough grinding process shown in FIGS. **6**A and **6**B;

FIGS. **8**A and **8**B are a front elevational view and a plan view illustrating a finish grinding process;

FIGS. **9**A And **9**B are partial side elevational views illustrating in enlarged form the finish grinding process shown in FIGS. **8**A and **8**B;

FIG. **10** is an enlarged cross-sectional view of a modification of a workpiece holding mechanism of the grinding apparatus shown in FIG. **1**;

FIG. **11** is an enlarged plan view of a modification of a grinding mechanism of the grinding apparatus shown in FIG. **1**;

FIGS. **12**A to **12**C are plan views illustrating modifications of a grinding wheel head;

FIG. **13** is a cross-sectional view illustrating a modification of the grinding process;

FIG. **14** is a front elevational view illustrating a modification of the grinding apparatus;

FIG. **15** is a plan view illustrating the modification of the grinding apparatus shown in FIG. **14**; and

FIG. **16** is an explanatory diagram illustrating a conventional method of grinding a workpiece.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. **1** to **9**B, a description will be given of an embodiment of the invention.

As shown in FIGS. **1** to **3**, a column **22** is provided uprightly on a bed **21** of the grinding apparatus, and a workpiece holding mechanism **24** serving as a workpiece holding means for holding a workpiece **23** formed of a circular thin plate such as a semiconductor wafer is disposed on the column **22**. A grinding mechanism **25** serving as a grinding means is disposed on the bed **21** in correspondence with the workpiece holding mechanism **24**. This grinding mechanism **25** is provided with a rotating grinding wheel **26** for cylindrical grinding for the rough cutting of an outer peripheral edge portion **23***a* of the workpiece **23** as well as two disk-shaped rotating grinding wheels **27** and **28** for the rough grinding and finish grinding of the outer peripheral edge portion **23***a* of the workpiece **23**.

It should be noted that, in this embodiment, a rotating grinding wheel which is formed by binding the grains of silicon dioxide (SiO_2) with a bond to form the silicon dioxide into fixed abrasive grains is used as the aforementioned rotating grinding wheel **28** for finishing.

On the left side of the grinding mechanism **25**, a carrying-in station **29** is disposed on the bed **21**, and a cassette **30** accommodating a plurality of u,machined workpieces **23** is carried into this carrying-in station **29**. A first working robot **31** is installed in the rear of the carrying-in station **29**, and the unmachined workpieces **23** are fetched one by one from the cassette **30** by the first working robot **31**, and are delivered to the workpiece holding mechanism **24**.

As shown in FIG. **1**, a thickness measuring sensor **202** of a contact type for measuring the thickness of the workpiece **23** is disposed above the carrying-in station **29**. By using four sensor elements **202***a*, **202***b*, **202***c*, and **202***d*, the thickness measuring sensor **202** measures the thickness of an outer periphery of one workpiece **23** at a time, and detects defective workpieces. Further, on the basis of the measured thickness, a controller **201** computes the center in the thicknesswise direction of the workpiece **23**, and determines a reference position for feeding the workpiece **23** in a Z direction.

On the right side of the grinding mechanism **25**, a carrying-out station **32** is disposed on the bed **21**, and a cleaning mechanism **33** is provided in its lower portion. A second working robot **34** is installed in the rear of the carrying-out station **32**, and the machined workpieces **23** are received by the second working robot **34** from the workpiece holding mechanism **24** and, after going through the cleaning mechanism **33**, are accommodated in the cassette **30** on the carrying-out station **32**.

An outside-diameter measuring sensor **206** is disposed above the carrying-out station **32**. It should be noted that, in FIG. **1**, the outside-diameter measuring sensor **206** is illustrated not above the carrying-out station **32**, but in a different position for the sake of description. The outside-diameter measuring sensor **206** measures the outside diameter of the workpiece **23** by causing an abutting plate **206***a* and a pushing plate **206***b* provided with a sensor element to come into contact with the workpiece, the abutting plate **206***a* and the pushing plate **206***b* being respectively provided at two points located in correspondence with the diameter of the workpiece. On the basis of the measured outside diameter, the controller **201** confirms the finish of the workpiece **23**.

Next, a detailed description will be given of the details of the arrangement of the workpiece holding mechanism **24**. As shown in FIG. **3**, a work head **37** is supported on a side surface of the column **22** in such a manner as to be movable in the Z-axis direction (in the vertical direction) through a guide rail **38** via rolling bearings. A rotating shaft **39** is supported on the work head **37** in such a manner as to be rotatable about the axis L1 extending in the Z-axis direction, and a suction pad **40** for sucking and holding the workpiece **23** is provided at a lower end thereof.

A workpiece rotating motor **41** is disposed on top of the work head **37**, and the rotating shaft **39** is rotated by the motor **41**, which in turn causes the workpiece **23** sucked and held onto the suction pad **40** to rotate about its center as the axis L1. A Z-axis moving motor **42** is disposed on top of the column **22**, and a ball screw **43** is rotated by the motor **42**, which in turn causes the work head **37** to move in the Z-axis direction through a connecting arm **45** attached to a nut **44**.

Next, a description will be given of the details of the arrangement of the grinding mechanism **25**. As shown in FIGS. **2** and **3**, a supporting table **47** is disposed on the bed **21** in such a manner as to be movable in the X-axis direction (in a longitudinal direction) along a pair of guide rails **48** via rolling bearings. A saddle **49** is supported on the supporting table **47** in such a manner as to be movable in the Y-axis direction (in a transverse direction) along a pair of guide rods **50** via rolling bearings.

An X-axis moving motor **51** is disposed on the bed **21**, and a ball screw **52** is rotated by the motor **51**, which in turn causes the supporting table **47** to move in the X-axis direction through a nut **53**. A Y-axis moving motor **54** is disposed in the rear of the supporting table **47**, and a ball screw **55** is rotated by the motor **54** to move the saddle **49** in the Y-axis direction through a nut **56**. The X-axis moving motor **51**, the Y-axis moving motor **54**, and the Z-axis moving motor **42** are subjected to numerical control, and permit automatic control on the basis of an NC program.

A first-grinding-wheel rotating motor **57** is disposed on top of the supporting table **47** on the left-hand side thereof, and the aforementioned rotating grinding wheel **26** for cylindrical grinding is mounted on a motor shaft **58** projecting from its upper surface. This rotating grinding wheel **26** for cylindrical grinding is rotated about the axis L2 parallel to the central axis L1 of the workpiece **23** by the first-grinding-wheel rotating motor **57**.

A second-grinding-wheel rotating motor **59** is disposed on the saddle **49**, and the aforementioned disk-shaped rotating grinding wheel **27** for rough grinding and rotating grinding wheel **28** for finish grinding are mounted on a motor shaft **60** projecting on a left side surface of the second-grinding-wheel rotating motor **59** at a predetermined interval therebetween. The rotating grinding wheel **27** for rough grinding and the rotating grinding wheel **28** for finish grinding are rotated about an axis L3 parallel to the plane of the workpiece **23** by the second-grinding-wheel rotating motor **59**.

The grinding mechanism **25** is provided with a workpiece-outside-diameter measuring sensor **203** of a contact type for measuring the outside diameter of the workpiece **23** after the rough cutting process, a grinding-wheel-diameter measuring sensor **204** for measuring the diameters of the rotating grinding wheel **27** for rough grinding and the rotating grinding wheel **28** for finish grinding, and a Z-direction position measuring sensor **205** for detecting the position of the workpiece **23** in the Z direction.

The workpiece-outside-diameter measuring sensor **203** is disposed in the vicinity of the first-rotating-wheel rotating motor **57** so as to measure the outside diameter of the workpiece **23** after the rough cutting process. On the basis of the measured outside diameter of the workpiece **23**, the controller **201** detects the amount of wear of the rotating grinding wheel **26** for cylindrical grinding. The controller.**201** adjusts the amount of feed of the grinding wheel **26** in the x direction so that the depth of cut into the workpiece **23** becomes constant in the rough cutting process. In addition, if the workpiece **23** is not ground by a predetermined amount, the controller **201** determines that the wear of the grinding wheel **26** is large, and warns the operator to replace the grinding wheel **26**. Further, a mounting base for mounting the sensor **203** as well as the workpiece holding mechanism **24** including the rotating shaft **39**, the suction pad **40**, and the like expand due to heat generated during the grinding process, exerting adverse effects on the measurement. For this reason, to compensate for their displacements caused by the thermal expansion, zero adjustment is performed for adjusting the relative positions of the sensor **203** and the suction pad **40**. This zero adjustment is effected by causing the sensor **203** to abut against an outer peripheral edge portion of the suction pad **40**.

The grinding-wheel-diameter measuring sensor **204** is disposed radially outwardly of the rotating grinding wheel **27** for rough grinding or the rotating grinding wheel **28** for finish grinding so as to measure the outside diameters of the grinding wheels **27** and **28**. The controller **201** detects the amounts of wear of the grinding wheels **27** and **28** from the measured outside diameters of the grinding wheels **27** and **28**, and adjusts the amount of feed of the grinding wheels **27** and **28** in the Y direction and the amount of feed of the workpiece **23** in the Z direction. Further, if it is determined that the amounts of wear of the grinding wheels **27** and **28** are large, the controller **201** warns the operator to replace the grinding wheels **27** and **28**. In the case of the grinding-wheel-diameter measuring sensor **204** as well, to compensate for displacements due to the thermal expansion of a mounting base for mounting the sensor **204**, the motor shaft **60** for mounting the grinding wheels **27** and **28**, and the like, zero adjustment is performed for adjusting the relative positions of the sensor **204** and the grinding wheels **27** and **28**. This zero adjustment is effected by causing the sensor **204** to abut against a block provided on a bearing housing of the motor shaft **60** for mounting the grinding wheels **27** and **28**.

The Z-direction position measuring sensor **205** is disposed on the housing side of the motor **59** so as to face the lower surface of the suction pad **40**, and measures the Z-direction position of the suction pad **40** at its reference position in a non-contact manner as the Z-direction position measuring sensor **205** is positioned in such a manner as to oppose the lower surface of the suction pad **40** in a state in which the workpiece **23** is not fitted to the suction pad **40**. On the basis of the Z-direction position of the workpiece **23**, the controller **201** detects the elongation in the Z direction of the workpiece holding mechanism **24** including the rotating shaft **39**, the suction pad **40**, and the like due to their thermal expansion, and adjusts the reference position for feeding the workpiece **23** in the Z direction.

In addition, to maintain the relative positional relationship in the Y direction between the workpiece **23** and the grinding wheels **27** and **28** constant, a Y-direction position measuring sensor may be provided radially outwardly of the suction pad **40** so as to compensate for the relative displacements due to the thermal expansion of the Y-direction feeding mechanism for the grinding wheels **27** and **28** and the workpiece holding mechanism **24**. In this case, the Y-direction position at the Y-direction reference position is measured in a non-contact manner with respect to a reference point provided on the saddle **49** or the housing of the motor **59**. Alternatively, the Y-direction position measuring sensor may be disposed on a side of the saddle **49** or the housing of the motor **59**. On the basis of the Y-direction position of the workpiece **23**, the controller **201** detects the elongation in the Y-direction of the Y-direction feeding mechanism and the workpiece holding mechanism **24** due to their thermal expansion, and adjusts the reference position for feeding the workpiece **23** in the Y direction.

Next, a description will be given of the method of grinding in the case where the outer peripheral edge **23***a* of the workpiece **23** is ground by using the grinding apparatus having the above-described construction.

In the method of grinding a workpiece, as shown in FIGS. **4**A to **4**C, the outer peripheral edge **23***a* of the workpiece **23** is ground separately in three processes. Namely, first, the outer peripheral edge portion **23***a* of the workpiece **23** is subjected to rough cutting by the rotating grinding wheel **26** for cylindrical grinding, as shown in FIG. **4**A. Next, as shown in FIG. **4**B, the outer peripheral edge portion **23***a* after its rough cutting is subjected to rough grinding by the disk-shaped rotating grinding wheel **27** for rough grinding. Subsequently, the outer peripheral edge portion after its rough grinding is subjected to finish grinding by the rotating grinding wheel **28** for finish grinding, as shown in FIG. **4**C.

Accordingly, a detailed description will be given of the rough cutting process. As shown in FIGS. **5**A and **5**B, the workpiece **23** is moved and disposed at a heightwise position corresponding to the rotating grinding wheel **26** for cylindrical grinding by the Z-axis moving motor **42** in a state in which the workpiece **23** is being sucked and held onto the suction pad **40** of the workpiece holding mechanism **24**. In this state, the workpiece **23** is rotated about the axis L1 by the workpiece rotating motor **41**, and the rotating grinding wheel **26** for cylindrical grinding is rotated about the axis L2 parallel to the central axis L1 of the workpiece **23** by the first-rotating-wheel rotating motor **57**. At the same time, the rotating grinding wheel **26** for cylindrical grinding is moved to be fed toward the outer peripheral edge portion **23***a* of the workpiece **23** by the X-axis moving motor **51**. Consequently, the outer peripheral edge portion **23***a* of the workpiece **23** is subjected to rough cutting by cylindrical grinding, as shown by the chain lines in FIGS. **4**A and **5**B.

In the rough cutting process, a forming grinding wheel as shown in FIG. **5**C can be used as the rotating grinding wheel **26** for cylindrical grinding so as to reduce the grinding amount in the following rough grinding process.

Subsequently, in the rough grinding process, as shown in FIGS. **6**A and **6**B, the rotating grinding wheel **27** for rough grinding is moved and disposed by the X-axis moving motor **51** at a position corresponding to a line L4 passing through the axis L1 of the workpiece **23** in the X direction while the workpiece **23** is sucked and held onto the suction pad **40**. In this state, the workpiece **23** is rotated by the workpiece rotating motor **41**, and the rotating grinding wheel **27** for rough grinding is rotated about the axis L3 extending in a direction parallel to the plane of the workpiece **23** and perpendicular to the radial direction of the workpiece **23** by the second-rotating-wheel rotating motor **59**.

At the same time, the workpiece **23** is moved in the Z-axis direction by the Z-axis moving motor **42** on the basis of a predetermined NC program, and the rotating grinding wheel **27** for rough grinding is moved in the Y-axis direction by the Y-axis moving motor **54**. Through this simultaneous two-axes control, the rotating grinding wheel **27** is moved to be fed with respect to the workpiece **23** in such a manner as to depict a predetermined locus of movement between the obverse and reverse surfaces of the workpiece **23** along the outer peripheral edge portion **23***a* of the workpiece **23**, as shown in FIG. **7**. Consequently, as shown by the chain lines in FIGS. **4**B, **6**B, and **7**, the outer peripheral edge portion **23***a* of the workpiece **23** is subjected to rough grinding by the outer peripheral wheel surface of the rotating grinding wheel **27** in the same station as that for the above-described rough cutting process in such a manner as to form a tapered profile with an arcuate peripheral edge portion in its cross section.

Further, in the finish grinding process, as shown in FIGS. **8**A and **8**B, the rotating grinding wheel **28** for finish grinding is moved and disposed by the X-axis moving motor **51** at a position corresponding to the line L4 in the X-direction while the workpiece **23** is sucked and held onto the suction pad **40**. In this state, the workpiece **23** is rotated by the workpiece rotating motor **41**, and the rotating grinding wheel **28** for finish grinding is rotated about the axis L3 by the second-grinding-wheel rotating motor **59**.

At the same time, the workpiece **23** is moved in the Z-axis direction by the Z-axis moving motor **42** on the basis of the predetermined NC program, and the rotating grinding wheel **28** for finish grinding is moved in the Y-axis direction by the Y-axis moving motor **54**. Through this simultaneous two-axes control, the rotating grinding wheel **28** is moved to be fed with respect to the workpiece **23** in such a manner as to depict a predetermined locus of movement between the obverse and reverse surfaces of the workpiece **23** along the outer peripheral edge portion **23***a* of the workpiece **23**, as shown in FIGS. **9**A and **9**B. Consequently, as shown by the chain lines in FIGS. **4**C, **8**B, **9**A, and **9**B, the outer peripheral edge portion **23***a* of the workpiece **23** is subjected to finish grinding into a desired profile by the outer peripheral wheel surface of the rotating grinding wheel **28** in the same station as that for the above-described rough cutting process and rough grinding process.

In this case, as shown in FIGS. **9**A and **9**B, crystal orientation **23***b* extends in the workpiece **23** substantially in parallel with the obverse and reverse surfaces of the workpiece **23**, and different angles of the crystal face appear in the outer peripheral edge portion **23***a* of the workpiece **23** from both obverse and reverse surface sides to the tip of the edge portion. For this reason, it is necessary to effect grinding by changing the grinding conditions (the feeding speed in grinding movement, the rotating speeds of the workpiece **23** and the grinding wheel **28**, etc.) in accordance with the angles of the crystal face. By adopting a grinding method in which a machining step over the obverse and reverse surfaces is bisected as shown in FIGS. **9**A and **9**B, and the feed-moving direction of the rotating grinding wheel **28** for finish grinding and the rotating direction of the rotating grinding wheel **28** are changed with respect to the outer peripheral edge portion **23***a* of the workpiece **23** so as to depict mutually symmetrical loci of movement, it becomes possible to effect grinding by the same change of the grinding conditions for both the obverse and reverse surface sides, and it is possible to prevent the occurrence of variations in the roughness of the ground surface between the obverse surface side and the reverse surface side of the edge portion.

Specifically, the outer peripheral edge portion **23***a* of the workpiece **23** is not ground continuously between the obverse and reverse surfaces sides thereof, and finish grinding is effected separately for the obverse surface side and the reverse surface side. Namely, as shown in FIG. **9**A, first, the rotating grinding wheel **28** for finish grinding, while being rotated in one direction, is moved to be fed toward the outer peripheral edge portion **23***a* of the workpiece **23** starting with its obverse surface side and then toward its tip side, thereby subjecting the obverse surface side of the outer peripheral edge portion **23***a* to finish grinding. Subsequently, as shown in FIG. **9**B, the rotating grinding wheel **28**, while being rotated in the opposite direction, is moved to be fed toward the outer peripheral edge portion **23***a* of the workpiece **23** starting with its reverse surface side and then toward its tip side, thereby subjecting the reverse surface side of the outer peripheral edge portion **23***a* to finish grinding.

Further, after the outer peripheral edge portion **23***a* of the workpiece **23** is subjected to finish grinding as described above, the workpieces **23** in a state of being accommodated in the cassette **30** are transported from the grinding apparatus to another station. In this other station, the final finishing of the outer peripheral edge portion **23***a* of the workpiece **23** is effected by using an unillustrated disk-shaped polishing pad and slurry. Namely, an outer peripheral surface of the disk-shaped polishing pad is caused to abut against the outer peripheral surface of the workpiece **23** in the same way as the rotating grinding wheels **27** and **28**. At the same time, slurry which is prepared by mixing abrasive grains into a dispersant is supplied to a gap between the polishing pad and the workpiece **23**. By so doing, the edge portion **23***a* of the workpiece **23** is subjected to super-finish grinding by the grains in the slurry.

(Modifications)

It should be noted that this embodiment may be embodied by making the following modifications.

(a) In the grinding apparatus of the above-described embodiment, the work head **37** and the saddle **49** are respectively movably supported to the guide cylinder **140** and the guide rod **50** by means of hydrostatic bearings **142**, **146** and **180**.

A description will be given of the work holding mechanism **24** including the hydrostatic bearings in detail. As shown in FIG. **10**, the guide cylinder **140** is attached to a side of the column **22** in such a manner as to extend in the vertical direction (in the Z direction). A supporting cylinder **141** is supported in the guide cylinder **140** by means of hydrostatic bearings **142** in such a manner as to be movable in the Z direction, and a pair of bearing cylinders **143** and **144** are disposed in the supporting cylinder **141**. A supporting shaft **145** is supported in the bearing cylinders **143** and **144** by means of hydrostatic bearings **146** in such a manner as to be rotatable and liftable. An air passage **145***a* is formed in its center, and the air passage **145***a* is connected to a vacuum pump (not shown) through a hose **145***b*.

A suction pad **147** is fixed to a lower end of the supporting shaft **145** by means of bolts (not shown). In the center of the suction pad **147**, there is formed an air passage **147***a* communicating with the air passage **145***a* of the supporting shaft **145**. Further, in the lower surface thereof, there is formed a plurality of suction grooves **147***b* communicating with the air passage **147***a*. A motor **148** for rotation is disposed within the supporting cylinder **141**, a stator **148***a* thereof is fixed to the supporting cylinder **141**, and a rotor **148***b* thereof is fixed to the supporting shaft **145**. The suction pad **147** is rotated by the motor **148** for rotation via the supporting shaft **145**.

A motor **42** for movement is disposed above the column **22**, and a ball screw **43** is projectingly provided on a lower portion of the motor **42**. A connecting arm **45** is projectingly provided on an outer periphery of the supporting cylinder **141**, and a nut **44** meshing with the ball screw **43** is attached to a distal end of the connecting arm **45**. As the ball screw **43** is rotated by the motor **42** for movement, the supporting cylinder **141** is moved vertically by means of the nut **44**, thereby moving the suction pad **147** vertically.

For this reason, when the workpiece **23** is moved at least in the Z direction, the relative movement of the disk-shaped rotating grinding wheels **27** and **28** and the workpiece **23** is effected smoothly by the guide mechanism including the hydrostatic bearings **142** and **146**. Accordingly, compared with a guide mechanism including rolling bearings, it is possible to prevent the vibrations from occurring during the relative movement of the disk-shaped rotating grinding wheels **27** and **28** and the workpiece **23**, thereby making it possible to improve the processing accuracy of the ground surface of the workpiece **23**.

The guide mechanism including the hydrostatic bearings **180** is also provided in the arrangement for moving the grinding mechanism **25** in the Y direction. For this reason, when the rotating grinding wheels **27** and **28** and the workpiece **23** are relatively moved in the Y direction within the plane including the rotational axis of the disk-shaped rotating grinding wheels **27** and **28**, the relative movement of the rotating grinding wheels **27** and **28** and the workpiece **23** is effected smoothly by the guide mechanism including the hydrostatic bearings **180**. Accordingly, it is possible to prevent the vibrations from occurring during the relative movement of the rotating grinding wheels **27** and **28** and the workpiece **23** in the Y direction as well, thereby making it possible to further improve the processing accuracy of the ground surface of the workpiece **23**.

The hydrostatic bearings **146** are also provided in the mechanism for supporting the rotation of the workpiece **23**. For this reason, the workpiece **23** is supported so as to rotate smoothly, thereby making it possible to further improve the processing accuracy of the ground surface of the workpiece **23**.

(b) In the grinding apparatus of the above-described embodiment, as shown in FIG. **12**A, the second-grinding-wheel rotating motor **59** is supported on the saddle **49** by means of a supporting shaft **63** in such a manner as to be capable of undergoing indexed rotation, and the rotating grinding wheel **27** for rough grinding and the rotating grinding wheel **28** for finish grinding are respectively mounted on the motor shafts **60** projecting from left and right opposite side surfaces of the motor **59**.

In this arrangement, since the second-grinding-wheel rotating motor **59** is made to undergo indexed rotation, either one of the rotating grinding wheel **27** for rough grinding and the rotating grinding wheel **28** for finish grinding is disposed at the position corresponding to the axis L1 of the workpiece **23**. Then, in this state of corresponding displacement, the rough grinding and finish grinding of the outer peripheral edge portion **23***a* of the workpiece **23** can be performed consecutively by the same station.

(c) In the grinding apparatus of the above-described embodiment, as shown in FIG. **12**B, the disk-shaped rotating grinding wheel **27** for rough grinding and rotating grinding wheel **28** for finish grinding as well as a polishing pad **64** are mounted at predetermined intervals on the motor shaft **60** projecting from the left side surface of the second-rotating-wheel rotating motor **59**.

If such an arrangement is provided, after the outer peripheral edge portion **23***a* of the workpiece **23** is subjected to rough grinding and finish grinding by using the rotating grinding wheel **27** for rough grinding and the rotating grinding wheel **28** for finish grinding, the final finishing of the outer peripheral edge portion **23***a* can be performed in the same station as that for these grinding operations by using the polishing pad **64** and slurry.

(d) In the grinding apparatus of the above-described embodiment, as shown in FIG. **12**C, the second-rotating-wheel rotating motor **59** is supported on the saddle **49** by means of a supporting shaft **63** in such a manner as to be capable of undergoing indexed rotation, and the rotating grinding wheel **27** for rough grinding, the rotating grinding wheel **28** for finish grinding, and the polishing pad **64** are mounted on the motor shafts **60** projecting from the left and right opposite side surfaces and rear surface of the motor **59**.

In this arrangement, since the second-rotating-wheel rotating motor **59** is made to undergo indexed rotation, any one of the rotating grinding wheel **27** for rough grinding, the rotating grinding wheel **28** for finish grinding, and the polishing pad **64** is disposed at the position corresponding to the axis L1 of the workpiece **23**. Then, in this state of corresponding displacement, the rough grinding, finish grinding, and final finishing of the outer peripheral edge portion **23***a* of the workpiece **23** can be performed consecutively by the same station.

(e) In the grinding apparatus of the above-described embodiment, as the rotating grinding wheel **27** for rough grinding as well, it is possible to use a rotating grinding wheel which is formed by binding the grains of silicon dioxide into fixed abrasive grains in the same way as the rotating grinding wheel **28** for finish grinding.

(f) As the fixed abrasive grains of the rotating grinding wheel **28** for finish grinding, silicon carbide or the like which is generally used is employed.

(g) In the grinding apparatus of the above-described embodiment, the rough grinding of the outer peripheral edge portion **23***a* of the workpiece **23** by the rotating grinding wheel **27** for rough grinding is also performed separately for the obverse surface side and the reverse surface side of the outer peripheral edge portion **23***a* in the same way as finish grinding shown in FIGS. **9**A and **9**B.

(h) In the grinding apparatus of the above-described embodiment, a forming grinding wheel is used as the rotating grinding wheel **26** for rough cutting.

(i) A Z-axis direction moving mechanism is provided on the grinding wheel **27**,**28** side, and the outer peripheral edge portion **23***a* of the workpiece **23** is ground by the feed movement in the Z-axis direction and the Y-axis direction of the grinding wheel **27**,**28** side without moving the workpiece **23**. Alternatively, the workpiece **23** side is movable in the X-axis direction and in the Y-axis direction, while the grinding wheel **27**,**28** side is made movable in the Z-axis direction.

(j) As shown in FIG. **13**, a workpiece having a circular hole **23***c* in its center is used as the workpiece **23**, a peripheral edge of the circular hole **23***c*, i.e., an inner peripheral edge portion **23***d*, is ground in addition to the outer peripheral edge portion **23***a*. Namely, the workpiece **23** is sucked onto the suction pad **40** having a space **40***a* in its central portion, a smaller rotating grinding wheel **27** for rough grinding or rotating grinding wheel **28** for finish grinding is relatively moved to be fed between the obverse and reverse surface sides of the workpiece **23** in the same way as the above-described grinding of the outer peripheral edge portion **23***a*, thereby making it possible to grind the inner peripheral edge portion **23***d*. In this case, it is possible to continuously perform the grinding of the outer peripheral edge portion **23***a* and the inner peripheral edge portion **23***d* of the workpiece **23** by using the same grinding wheel in the same machining station, so that the arrangement of the apparatus is made compact, and the machining shape accuracy can be improved.

(k) In the grinding method of the above-described embodiment, the rough grinding process and the finishing grinding process can be performed in a grinding apparatus shown in FIGS. **14** and **15**.

In the grinding apparatus shown in FIGS. **14** and **15**, a pair of bases **121** and **122** are connected to each other. A workpiece holding mechanism **24** and a grinding mechanism **25** are disposed on the first base **121**, so that an outer periphery of a workpiece **23** as a circular thin plate, which is sucked and held by the workpiece holding mechanism **24**, is ground by the grinding mechanism **25**.

A wafer carrying mechanism **129** including a first moving table **133** and a second moving table **134** is disposed on the second base **122**. The first moving table **133** is disposed in such a manner as to be movable between a processing position P**3** corresponding to the workpiece holding mechanism **24** and a retreated position P2 at a distance therefrom. Further, the second moving table **134** is supported on the first moving table **133** in such a manner as to be integrally and relatively movable with the first moving table 133. An unprocessed workpiece **23** is carried onto the workpiece holding mechanism **24** by the first moving table **133**, and a processed workpiece **23** is carried out from the workpiece holding mechanism **24** by the second moving table **134**.

A cover **135** is provided over the two bases **121** and **122** in such a manner as to cover the various mechanism sections on their upper surfaces, and a shutter **136** is disposed in a substantially intermediate portion thereof in such a manner as to be capable of being lowered or raised. During the grinding of the workpiece **23**, the shutter **136** is closed so that the portions on the first base **121** and the portions on the second base **122** are separated, thereby preventing a coolant and the like from being scattered to the portions on the base **122**. In addition, the shutter **136** is opened when the workpiece **23** is carried in or carried out by the wafer carrying mechanism **129**.

In the grinding mechanism **25** of this modification, as shown in FIG. **15**, a supporting base **160** for shifting is disposed on the first base **121**, and a pair of guide rails **161** for shifting are laid on an upper surface of the supporting base **160** in such a manner as to extend within a horizontal plane in a diagonally shifting direction S from the front on the left-hand side toward the rear on the right-hand side. A shifting base **162** is shiftably supported on the guide rails **161** for shifting, and a pair of X-direction guide rails **163** extending in the left-and-right direction (X direction) within the horizontal plane are laid on an upper surface of the shifting base **162**.

A moving base **164** is movably supported on the X-direction guide rails **163** by means of a pair of rolling units, and a pair of Y-direction guide rods **165** extending in the Y direction within the horizontal plane are disposed on an upper portion of the moving base **164**. A saddle **166** is movably supported on the Y-direction guide rods **165** by means of hydrostatic bearings. In addition, a processing head **167** is supported on an upper portion of the Y-direction guide rods **165** through a supporting shaft **168** in such a manner as to be capable of swiveling about a vertical axis by means of a motor and a ball screw. A pair of rotating shafts **169** and **170** are projectingly provided on both sides of the processing head **167** in such a manner as to extend in a horizontal direction perpendicular to the axis of the supporting shaft **168**, and the rotating shafts **169** and **170** are rotated by a motor **171** accommodated in the processing head **167**. Then, the rotating grinding wheel **27** for rough grinding is mounted on the rotating shaft **169**, while the rotating grinding wheel **28** for finish grinding is mounted on the other rotating shaft **170**. It should be noted that the hydrostatic bearings are used only for the Z and Y axes related to processing for the purpose of the reduction of cost. But, the hydrostatic bearings may be used also at the time of relatively moving the rotating grinding wheels **27** and **28** in the X direction and in the S direction.

A description will now be given of the advantages which can be expected from the above-described embodiment.

In the method of grinding a workpiece in this embodiment, the workpiece **23** formed of a circular thin plate is rotated about its center as the axis L**1**, and each of the disk-shaped rotating grinding wheels **27** and **28**, while being rotated about the axis L**3** substantially parallel to the plane of the workpiece **23**, is made to undergo relative and continuous feeding movement along at least one part of both obverse and reverse surface sides of the workpiece **23** on the outer peripheral edge portion **23***a* of the workpiece **23**. Consequently, the outer peripheral edge portion **23***a* of the workpiece **23** is ground by the outer peripheral wheel surface of each of the rotating grinding wheels **27** and **28**.

For this reason, as compared with the conventional grinding method in which the outer peripheral edge portion of the workpiece is ground by a forming grinding wheel, the profile of the wheel surface of each of the rotating grinding wheels

27 and 28 is less prone to deformation, so that it becomes unnecessary to replace the rotating grinding wheels 27 and 28 frequently. Accordingly, it is possible to reduce the material cost of the rotating grinding wheels 27 and 28, and hence the machining cost. Furthermore, since the profile of the wheel surface of each of the rotating grinding wheels 27 and 28 is less prone to deformation, the outer peripheral edge portions 23*a* of the workpieces 23 can be ground into constant machined shapes with high accuracy.

In addition, the edge portion 23*a* of the workpiece 23 can be finished into an arbitrary shape by the same grinding wheels 27 and 28 through the relative feeding control of the workpiece 23 and the rotating grinding wheels 27 and 28.

In the method of grinding a workpiece in this embodiment, the axis L3 of the rotating grinding wheels 27 and 28 is disposed in such a manner as to be perpendicular to the radial direction of the workpiece 23. For this reason, the rotation of the workpiece 23 is effected so as to traverse the outer peripheral surface of each of the rotating grinding wheels 27 and 28. In other words, the workpiece 23 undergoes relative movement in the widthwise direction of the rotating grinding wheels 27 and 28. Accordingly, it becomes possible to effectively grind all over the outer peripheral edge portion 23*a* of the workpiece 23 by making effective use of the overall width of the outer peripheral wheel surfaces of the rotating grinding wheels 27 and 28.

In the method of grinding a workpiece in this embodiment, the rotating grinding wheels consist of the two grinding wheels 27 and 28 for rough grinding and finish grinding, and rough grinding and finish grinding are performed by the grinding wheels 27 and 28, respectively. For this reason, the grinding of the outer peripheral edge portion 23*a* of the workpiece 23 can be effected separately for rough grinding and finish grinding and continuously and efficiently with high accuracy.

In the method of grinding a workpiece in this embodiment, the rough grinding and finish grinding of the outer peripheral edge portion 23*a* of the workpiece 23 are performed by the same station. For this reason, it becomes unnecessary to transport the workpiece 23 into another station or shift the holding of the workpiece 23, and it is possible to continuously perform rough grinding and finish grinding for the outer peripheral edge portion 23*a* in the state of being disposed in the same station. Hence, it is possible to maintain the positional accuracy of the workpiece and improve the operating efficiency. Further, stations for rough grinding and finish grinding need not be provided separately, the arrangement of the grinding apparatus can be simplified, and the grinding apparatus can be made compact.

In the method of grinding a workpiece in this embodiment, a rotating grinding wheel which is formed by binding the grains of silicon dioxide into fixed abrasive grains is used as the rotating grinding wheel 28 for finishing. For this reason, the outer peripheral edge portion 23*a* of the workpiece 23 can be ground with good finish-ground surface roughness by virtue of the chemical action based on the reducing action of silicon dioxide.

In the method of grinding a workpiece in this embodiment, the rotating grinding wheel 26 for cylindrical grinding is rotated about the axis L2 parallel to the central axis L1 of the workpiece 23 in the process preceding the grinding by the disk-shaped rotating grinding wheels 27 and 28, so as to roughly cut the outer peripheral edge portion 23*a* of the workpiece 23 by cylindrical grinding. For this reason, since the outer peripheral edge 10 portion 23*a* of the workpiece 23 is subjected to rough cutting in advance in the preceding process, the subsequent grinding of the outer-peripheral edge portion 23*a* of the workpiece 23 can be performed efficiently, thereby making it possible to improve the efficiency of the overall operation. Moreover, cylindrical grinding produces a large amount of grinding per unit time, the rough cutting can be performed efficiently, and since cylindrical grinding is rough cutting, even if the outer peripheral surface of the rotating grinding wheel 26 is slightly broken, machining accuracy remains substantially unaffected, so that the frequent replacement of the grinding wheel is unnecessary.

In the method of grinding a workpiece in this embodiment, after the outer peripheral edge portion 23*a* of the workpiece 23 is subjected to rough grinding and finish grinding by using the rotating grinding wheels 27 and 28, final finishing is performed in another station by using the disk-shaped polishing pad and slurry. For this reason, the pliability of the polishing pad contributes to high-accuracy machining, and the slurry cools the machined portion of the workpiece 23. Hence, it is possible to further enhance the ground surface roughness of the outer peripheral edge portion 23*a* of the workpiece 23 and effect super-finish grinding.

In the method of grinding a workpiece in this embodiment, the rotating grinding wheel 28 for finish grinding, while being rotated in one direction, is moved to be fed toward the outer peripheral edge portion 23*a* of the workpiece 23 starting with its obverse surface side and then toward its tip side, thereby subjecting the obverse surface side of the outer peripheral edge portion 23*a* to finish grinding. Subsequently, the rotating grinding wheel 28, while being rotated in the opposite direction, is moved to be fed toward the outer peripheral edge portion 23*a* of the workpiece 23 starting with its reverse surface side and then toward its tip side, thereby subjecting the reverse surface side of the outer peripheral edge portion 23*a* to finish grinding.

For this reason, it is possible to change the grinding conditions corresponding to the angle of the crystal face appearing in the outer peripheral edge portion 23*a* on the obverse surface side and the reverse surface side of the outer peripheral edge portion 23*a* of the workpiece 23, and it is possible to prevent the occurrence of variations in the roughness of the ground surface between the obverse surface side and the reverse surface side of the outer peripheral edge portion 23*a*. Hence, it is possible to grind the outer peripheral edge portion 23*a* of the workpiece 23 with uniform ground surface roughness and with high accuracy.

In the method of grinding a workpiece in this embodiment, the rotating grinding wheel, while being rotated in one direction, is moved to be fed toward the edge portion of the workpiece starting with its obverse surface side and then toward its tip side, to thereby grind the obverse surface side of the edge portion, and, subsequently, the rotating grinding wheel, while being rotated in the opposite direction, is moved to be fed toward the edge portion of the workpiece starting with its reverse surface side and then toward its tip side, to thereby grind the reverse surface side of the edge portion.

In accordance with this grinding method, since grinding is performed by bisecting an allowance for the obverse and reverse surfaces of the edge portion of the workpiece in such a manner as to depict symmetrical loci of movement on the obverse surface side and the reverse surface side, grinding can be performed by the same change of the grinding conditions for both the obverse and reverse surface sides in correspondence with the angle of the crystalline face appearing at the edge portion, and it is possible to prevent the occurrence of variations in the roughness of the ground surface between the obverse surface side and the reverse surface side of the edge portion. Hence, the edge portion of the workpiece can be ground uniform ground surface roughness with high accuracy. It should be noted that the dividing method is not confined to the bisection, and various dividing methods are conceivable including such as trisection into the obverse surface side, the reverse surface side, and the tip side, and a division into five parts of the obverse surface side, the reverse surface side, the tip side, a region between the obverse surface side and the tip side, and a region between the reverse surface side and the tip side. In such cases as well, the ground surface roughness of the obverse and reverse surface sides can be made uniform.

The present disclosure relates to the subject matter contained in Japanese Patent application Nos. Hei. 11-220019 filed on Aug. 3, 1999 and Hei. 11-91947 filed on Mar. 31, 1999 which are expressly incorporated herein by reference in its entirety.

While only certain embodiments of the invention have been specifically described herein, it will apparent that numerous modifications may be made thereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A method of grinding a workpiece, using a workpiece holding unit that includes a pad holding the workpiece, a rotating shaft attaching the pad at one end thereof, and a cylindrical member rotatably supporting the rotating shaft, comprising the steps of:

rotating the workpiece, formed of a circular thin plate about a center axis thereof, by rotating the rotating shaft and the pad holding the workpiece;

rotating a disk-shaped rotating grinding wheel about an axis thereof disposed substantially parallel to a plane of the workpiece; and

performing a relative feeding movement between the workpiece and said grinding wheel such said rotating grinding wheel moves along at least one part of an edge portion of the workpiece in a thickness direction of the workpiece, while concurrently rotating the workpiece and said rotating grinding wheel,

whereby an outer peripheral surface of said rotating grinding wheel grinds the edge portion of the workpiece.

2. The method according to claim **1**, wherein the axis of said rotating grinding wheel is disposed in such a manner as to be substantially perpendicular to a radial direction of the workpiece.

3. The method according to claim **1**, wherein said rotating grinding wheel includes a rotating grinding wheel for rough grinding and a rotating grinding wheel for finish grinding, whereby rough grinding and finish grinding are performed.

4. The method of grinding a workpiece according to claim **3**, wherein said rough grinding and said finish grinding are performed in a same station.

5. The method according to claim **3**, wherein at least said rotating grinding wheel for finish grinding includes grains of silicon dioxide binded into fixed abrasive grains.

6. The method according to claim **1**, wherein an outer peripheral edge portion of the workpiece is ground.

7. The method according to claim **6**, wherein a rotating grinding wheel for cylindrical grinding is rotated about an axis thereof disposed substantially parallel to the central axis of the workpiece in a process preceding the grinding by said disk-shaped rotating grinding wheel, so as to effect the rough cutting of the edge portion of the workpiece by cylindrical grinding.

8. The method according to claim **1**, wherein an inner peripheral edge portion of the workpiece having a circular hole in a center portion thereof is ground.

9. A method of grinding a workpiece, comprising the steps of:

rough cutting an edge portion of the workpiece formed of a circular thin plate by means of cylindrical grinding, said rough cutting step being obtained by rotating a first rotating grinding wheel for cylindrical grinding about an axis thereof disposed substantially parallel to a center axis of the workpiece, while rotating the workpiece about the center axis of the thereof; and

grinding the edge portion of the workpiece by an outer peripheral surface of a second rotating grinding wheel, said grinding step being obtained by performing a relative feeding movement between said second grinding wheel and the workpiece such that the second grinding wheel moves along at least one part of the edge portion of the workpiece in a thickness direction of the workpiece, while rotating said second rotating grinding wheel about an axis extending in a direction substantially parallel to a plane of the workpiece and substantially perpendicular to a radial direction of the workpiece.

10. The method according to claim **9**, wherein said second rotating grinding wheel includes a rotating grinding wheel for rough grinding and a rotating grinding wheel for finish grinding, and said grinding step includes rough grinding and finish grinding, which are performed after the rough cutting.

11. An apparatus for grinding a workpiece, comprising:

a workpiece holding unit holding the workpiece formed of a circular thin plate and rotating the workpiece about a center axis thereof;

a grinding unit having a disk-shaped rotating grinding wheel, said grinding unit grinding an edge portion of the workpiece by performing a relative feeding movement between said rotating grinding wheel and the workpiece such that said rotating grinding wheel moves along at least one part of the edge portion of the workpiece in a thickness direction thereof, while rotating said grinding stone about an axis thereof disposed substantially parallel to a plane of the workpiece; and

said workpiece holding unit includes:

a pad holding the workpiece;

a rotating shaft attaching said pad at one end thereof; and

a cylindrical member rotatably supporting said rotating shaft.

12. The apparatus according to claim **11**, further comprising:

a moving mechanism performing the relative movement between said rotating grinding wheel and the workpiece; and

a guide mechanism guiding the relative movement of said moving mechanism, said guide mechanism including a hydrostatic bearing.

13. The apparatus according to claim **12**, wherein said moving mechanism comprises:

a first moving mechanism performing a first relative linear movement between the workpiece and said rotating grinding wheel; and

a second moving mechanism performing a second relative linear movement between the workpiece and said rotating grinding wheel perpendicular to said first relative linear movement.

14. The apparatus according to claim **13**, wherein said guide mechanism guiding the first relative movement of said first moving mechanism includes said hydraulic bearing.

15. The apparatus according to claim **14**, wherein said guide mechanism guiding the second relative movement of said second moving mechanism includes said hydraulic bearing.

16. The apparatus according to claim **13**, wherein said workpiece holding unit includes said first moving mechanism, and

said grinding unit includes said second moving mechanism.

17. An apparatus for grinding a workpiece, comprising:

a workpiece holding unit holding the workpiece formed of a circular thin plate and rotating the workpiece about a center axis thereof;

a grinding unit having a disk-shaped rotating grinding wheel, said grinding unit grinding an edge portion of the workpiece by performing a relative feeding movement between said rotating grinding wheel and the workpiece such that said rotating grinding wheel moves along at least one part of the edge portion of the workpiece in a thickness direction thereof, while rotating said grinding stone about an axis thereof disposed substantially parallel to a plane of the workpiece;

a moving mechanism performing the relative movement between said rotating grinding wheel and the workpiece; and

a guide mechanism guiding the relative movement of said moving mechanism, said guide mechanism including a hydrostatic bearing;

wherein said moving mechanism comprises:

a first moving mechanism performing a first relative linear movement between the workpiece and said rotating grinding wheel; and

a second moving mechanism performing a second relative linear movement between the workpiece and said rotating grinding wheel perpendicular to said first relative linear movement; and

wherein said workpiece holding unit includes said first moving mechanism, and said grinding unit includes said second moving mechanism, and

wherein said workpiece holding unit includes:

a pad holding the workpiece;

a rotating shaft attaching said pad at one end thereof;

a cylindrical m ember rotatably supporting said rotating shaft; and

said hydrostatic bearings disposed between said rotating shaft and said cylindrical member.

18. An apparatus for grinding a workpiece, comprising:

a workpiece holding unit holding the workpiece formed of a circular thin plate and rotating the workpiece about a center axis thereof;

a grinding unit having a disk-shaped rotating grinding wheel, said grinding unit grinding an edge portion of the workpiece by performing a relative feeding movement between said rotating grinding wheel and the workpiece such that said rotating grinding wheel moves along at least one part of the edge portion of the workpiece in a thickness direction thereof, while rotating said grinding stone about an axis thereof disposed substantially parallel to a plane of the workpiece,

wherein said grinding unit includes:

a rough cutting unit having the rotating grinding wheel for cylindrical grinding, said rough cutting unit cutting the edge portion of the workpiece by performing a relative linear movement between the grinding wheel and the workpiece, while rotating the grinding wheel and the workpiece in the substantially same plane.

19. The apparatus according to claim **18**, further comprising:

a workpiece-outside-diameter measuring sensor measuring an outside diameter of the workpiece cut by said rough cutting unit,

wherein said relative linear movement between the other grinding wheel and the workpiece is determined in accordance with the measured outside diameter of the workpiece.

20. The apparatus according to claim **19**, wherein said workpiece-outside-diameter measuring sensor performs a zero adjustment for adjusting a relative position between said sensor and the workpiece for measuring.

21. The apparatus according to claim **11**, further comprising:

a grinding-wheel-diameter measuring sensor measuring the outside diameter of said rotating grinding wheel,

wherein said relative feeding movement is determined in accordance with the outside diameter of said rotating grinding wheel.

22. The apparatus according to claim **21**, wherein said grinding-wheel-diameter measuring sensor performs a zero adjustment for adjusting a relative position between said sensor and said rotating grinding wheel for measuring.

23. The apparatus according to claim **11**, further comprising:

a vertical position measuring sensor for measuring a vertical elongation of said workpiece holding unit.

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